AMRL-TR-76-8

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THE IMPULSE ACCELERATOR AN IMPACT SLED FACILITY FOR HUMAN RESEARCH AND SAFETY SYSTEMS TESTING

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DYNALECTRON CORP~~ORATION~~
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AUGUST 1976

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AEROSPACE MEDICAL RESEARCH LABORATORY
AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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AMRL-TR-76-8

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FOR THE COMMANDER

HENNING E. VON GIERKE
Director
Biodynamics and Bionics Division
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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER (18) (19) AMRL-TR-76-8	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	(9) Technical rept.
4. TITLE (and Subtitle) (6) THE IMPULSE ACCELERATOR An Impact Sled Facility for Human Research and Safety Systems Testing.	5. TYPE OF REPORT & PERIOD COVERED Nov 9 1972 – Aug 1 1975
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) John T. Shaffer	8. CONTRACT OR GRANT NUMBER(s) (15) F33615-74-C-4050
9. PERFORMING ORGANIZATION NAME AND ADDRESS Dynalectron Corporation 2901 Juan Tabo, N. E., Suite 225 Albuquerque, N. Mex. 87111	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62202F 72310644
11. CONTROLLING OFFICE NAME AND ADDRESS Aerospace Medical Research Laboratory, Aerospace Medical Division, Air Force Systems Command Wright-Patterson Air Force Base, Ohio 45433	12. REPORT DATE (11) August 1976 (12)
	13. NUMBER OF PAGES 79 87p.
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (16) AF-7231	15. SECURITY CLASS (of this report) U
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

(17) 723106

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

IMPACT
TEST FACILITIES
SAFETY

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The AMRL Impulse Accelerator impact test facility serves the needs of the USAF for research & development in crash safety & ejection seat testing. The facility located at Wright-Patterson AFB, Ohio, is used primarily for establishing tolerable human acceleration limits & developing protective restraint concepts. This report is basically an operations manual for the Impulse Accelerator System. It describes the operation and performance of the HYGE actuator, the instrumentation systems, the photo systems, the safety & control systems & the data reduction systems. Also included are descriptions of test set-up procedures & maintenance requirements.

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PREFACE

This report was produced under the sponsorship of the Impact Branch Aerospace Medical Research Laboratory at Wright-Patterson AFB, Ohio. The Impulse Accelerator is managed by the personnel of the Impact Branch. Mr. James W. Brinkley, branch chief, has been the primary person responsible for the success of the Facility. Under his guidance the facility was conceived and constructed in under 2 years. It should be a valuable research tool for many years to come.

Special recognition is also due the personnel at the Dynalectron Corporation, especially Mr. Charles Clark and Mr. Harold Boedeker who are responsible for the design and construction of many of the supporting systems.

The author wishes to thank Mr. Stan Rohrer for his assistance in producing the figures for this report and Mrs. Judy Lisle for her patience and the production of the manuscript.

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INTRODUCTION

The Impulse Accelerator impact test facility located in the Aerospace Medical Research Laboratory at Wright-Patterson AFB, Ohio, is a unique and important facility in the United States. Its primary function is to provide a versatile test platform for impact research as it relates to aircrew safety and survivability in crash and ejection. The U.S. Air Force has for many years been a leader in the development of safety systems for aircraft. The facility at Wright-Patterson is currently the only facility in the Air Force capable of testing many of the new concepts in crew safety. It is a system designed to allow the use of human volunteer test subjects and as such may be the most precise, well-controlled system of its kind ever assembled. Its use, however, is not restricted to safety research. Because of its weight capability, force capability, and inherent controllability it is a natural test facility for mechanical component impact survivability.

It has become apparent in the 4 years since its installation that its utilization will become more and more diversified. Personnel and groups of all disciplines have begun to make use of it. In order for this usage to be efficient, information on the facility must be available in a concise but comprehensive form. In addition, because operating personnel may change frequently, the operation, maintenance, and safety procedures need to be well documented along with the reasons particular methods are used. The purpose of this report is then two fold.

First, to provide in a concise, easily understood manner what the facility is capable of providing and how the user interfaces his test article. This is presented in the first section of the report. The remainder of the report contains the details of the actual operation of the facility and its various sub-systems. The backgrounds and reasons for using particular procedures are discussed. Sufficient detail is presented to allow a person to understand the interactions between the various control systems and to manage the operation and maintenance of the facility.

Because a facility of this nature must continually change and improve, specific details may vary from time to time. It is always good policy to verify the information contained herein before use.

DEMONSTRATED OPERATIONAL PARAMETER

IMPULSE ACCELERATOR

Payload	2000 lbs
Max. Acceleration	115 G (with 2000 lbs payload)
Max. Duration	0.175 sec
Max. Velocity	169 ft/sec
Max. Stroke	8.4 ft
Max. Dynamic Force	750,000 lbs
Nominal Sled Size	4 ft x 8 ft
Useable Track Length	130 ft
Waveforms	1/2 sine and trapezoidal
Minimum Braking Acceleration	0.3 G
Reproducibility	± 2%

INSTRUMENTATION SYSTEM

Primary Transducer Type	Bridge
No. of Data Channels	51 channels
Data Transmission Method	Hard wire
Analog Recording Capabity	50 channels

PHOTO SYSTEM

No. of On-board Cameras (16mm)	3
No. of Off-board Cameras (16mm)	5
Max. Lighting Power	100,000 watts
No. of High Speed Video Cameras	2

DATA REDUCTION SYSTEM

Quick Look Analog Traces	15 minutes after test
Max. A/D Conversion Rate	100,000 samples/sec
Computer Systems	Time/Data 1923
	EAI 380 Hybird
	HP 9830 A
	CDC 6600
Photo Reduction	PSC digitizer

GENERAL FACILITY DESCRIPTION

HISTORICAL

The United States Air Force has for many years been actively involved in research and development work in aircraft crash and ejection safety and impact injury prevention. Until 1969, this work was carried out jointly by the Aeromedical Research Laboratory (ARL) at Holloman Air Force Base, New Mexico and the Aerospace Medical Research Laboratory (AMRL) at Wright-Patterson Air Force Base, Ohio. The Holloman Laboratory was responsible for most of the crash research. It carried out this function utilizing primarily a linear deceleration track known as the Daisy Decelerator. The Wright-Patterson laboratory conducted most of its research into ejection seat safety and provided the interface between the aeromedical community and the systems development programs handled by the Aeronautical Systems Division, also at Wright-Patterson. The AMRL test facilities were vertical drop facilities useful for studying ejection accelerations. A horizontal impact track was not available at Wright-Patterson.

In 1969, the Air Force deactivated the Holloman laboratory. The crash test research program was transferred to Wright-Patterson. As the facilities at Wright-Patterson did not include a horizontal test track, the Daisy Decelerator at Holloman was maintained operational as a part of the AMRL. This remote operation was maintained for approximately 3 years. During this time studies were undertaken to decide the best way to move this portion of the research program to Wright-Patterson and consolidate all impact safety work into one physical location. These studies considered both the movement of the Daisy facility to Wright-Patterson and the construction of a totally new facility. The later choice was made for a number of reasons. There was no guarantee that the Daisy could be moved successfully. The age and characteristics of the Daisy facility made the movement and reinstallation a questionable project. The Daisy facility did not have the weight or performance capabilities required for future programs that were to be conducted. In addition, newer, more precision test facilities have been developed in recent years that could be purchased and installed for nearly the same cost as moving the Daisy facility.

For these reasons, a new horizontal test facility was purchased and installed at Wright-Patterson. The Daisy Facility was leased to New Mexico State University for research work in impact physiology.

The heart of the Wright-Patterson facility is a 24-inch HYGE actuator manufactured by the Bendix Corporation. One-hundred forty feet of track was installed with the facility. The facility is an acceleration track rather than a deceleration track as the Daisy facility had been. Smaller versions of this type of test track have been used for crash research for a number of years within the automobile industry.

The facility as it was initially installed contained only the instrumentation and controls required to fire the HYGE safely. To be useful as a research facility, a means for collecting accurate data was required. For human experimentation, a totally reliable and safe system for both operators and

test subjects was also required. Over the past 4 years the facility has been developed and upgraded to the complete impact test facility that is called the Impulse Accelerator. This facility includes not only the HYGE actuator but also automatic control systems capable of operating the actuator and collecting data in a reliable, safe manner.

MAJOR COMPONENTS

There are five major components within the Impulse Accelerator Facility. They are:

(1) Twenty-four inch HYGE actuator, sled and track system
(2) Instrumentation System
(3) Photo System
(4) Safety and Control System
(5) Data Reduction System

The heart of the system is the acceleration producing device and test platform, the HYGE. It is essentially a pneumatic actuator that pushes or impacts the sled along the track according to some predetermined profile.

The instrumentation system provides a means of collecting and recording data on the impact environment and test article responses. It is designed to handle many different types of transducers to provide accurate and flexible measures of the impact event.

The Photo System collects kinematic information on the response of the test articles. Both on-board and off-board cameras can be used with the system.

The Safety and Control System provides the functions for safely operating the Facility and controls the operation of,and correlation with,all other systems.

The Data Reduction System provides several means of analyzing the collected data. Some of the reductions are handled on-line with the impact event and others are designed for post-test analysis.

The following sections describe the operational details and guiding philosophies behind each of the systems and the interrelations amongst them. Subsequent sections will describe maintenance requirements, present some samples of test programs conducted on the Facility and look at the future development plan.

HYGE ACTUATOR AND SLED SYSTEM

GENERAL OPERATING PRINCIPLE

An exterior view of the Impulse Acceleration System is shown in Figure 1. The system consists of the HYGE actuator, test sled and track rails. The actuator produces forward thrust through differential gas pressures acting on opposite faces of a thrust piston in a closed cylinder. The cylinder is divided by an orifice plate into a rear or load chamber and a front or set chamber. Prior to firing, a low gas pressure (relative to the rear chamber pressure) forces the thrust piston against a seal ring on the orifice plate. The full area of the front of the thrust piston is exposed to the front chamber pressure, while only the relatively small area within the seal ring on the rear of the thrust piston is exposed to the high pressure in the rear chamber. The system is stable in this condition as the net force on the piston is acting rearward so as to maintain the seal. At firing, high pressure gas is introduced between the orifice and the rear of the thrust piston upsetting the seal. At this point the full area of the rear of the thrust piston is exposed to the high pressure gas in the rear chamber producing a large net forward force on the thrust column and sled combination. By controlling the manner in which the gas is metered through the orifice into the thrust chamber, the stroke length and the initial pressures, the resulting force and the acceleration imparted can be altered and controlled. After the initial acceleration, the test portion, the sled coasts to a stop along the track rails at a deceleration level much lower than the impact level.

This procedure is the reverse of the deceleration and condition produced by the Daisy Facility. On that facility, a test article is rapidly decelerated from a constant velocity to zero. The main advantage of an initial position at rest is that the test article may be positioned accurately prior to the test and is under no force before impact. The main disadvantage is that the test article experiences a long duration, low deceleration level subsequent to the impact that may contribute to the response.

ACTUATOR DETAILS

A cross sectional view of the actuator is shown in Figure 2. The inside diameter of both the front and rear cylinders is 24 inches. The wall thickness is approximately 2 inches. The rear cylinder is 11 feet long and the front cylinder is 16 feet long. Both cylinders are made from nickel-chronium molybdenum steel (AISI 4340).

An orifice plate separates the front and rear cylinders by 2 inches. The orifice contains passages for introducing load pressure into the load chamber, installation of a load pressure transducer and introducing trigger pressure.

Each cylinder contains a floating piston for changing the effective volumes of the load and set chambers. These changes are made by introducing or withdrawing hydraulic fluid from the cylinders through the cover plates. The hydraulic fluid transfer system used will be described later.

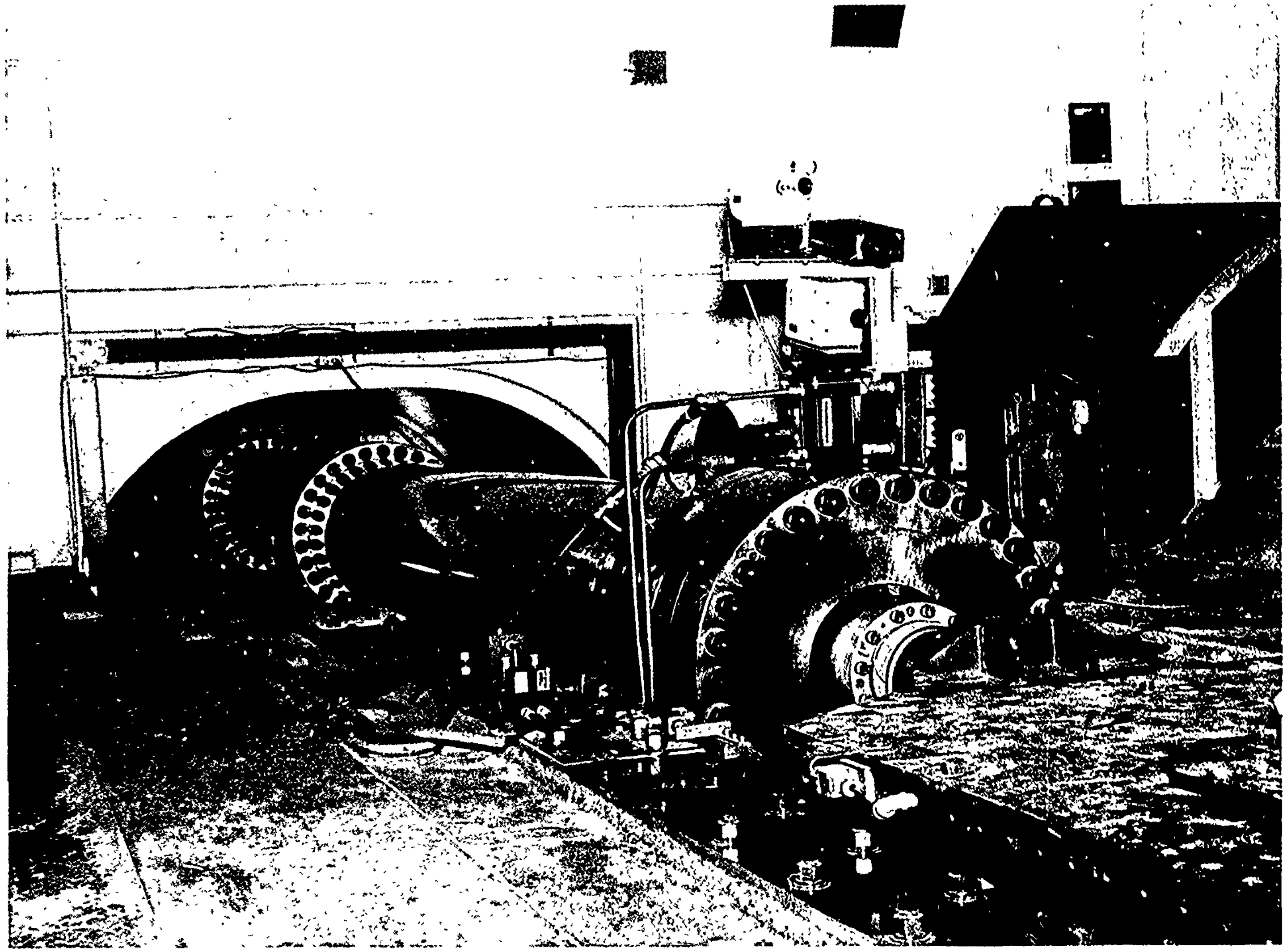


Figure 1 - EXTERIOR VIEW OF IMPULSE ACCELERATION SYSTEM

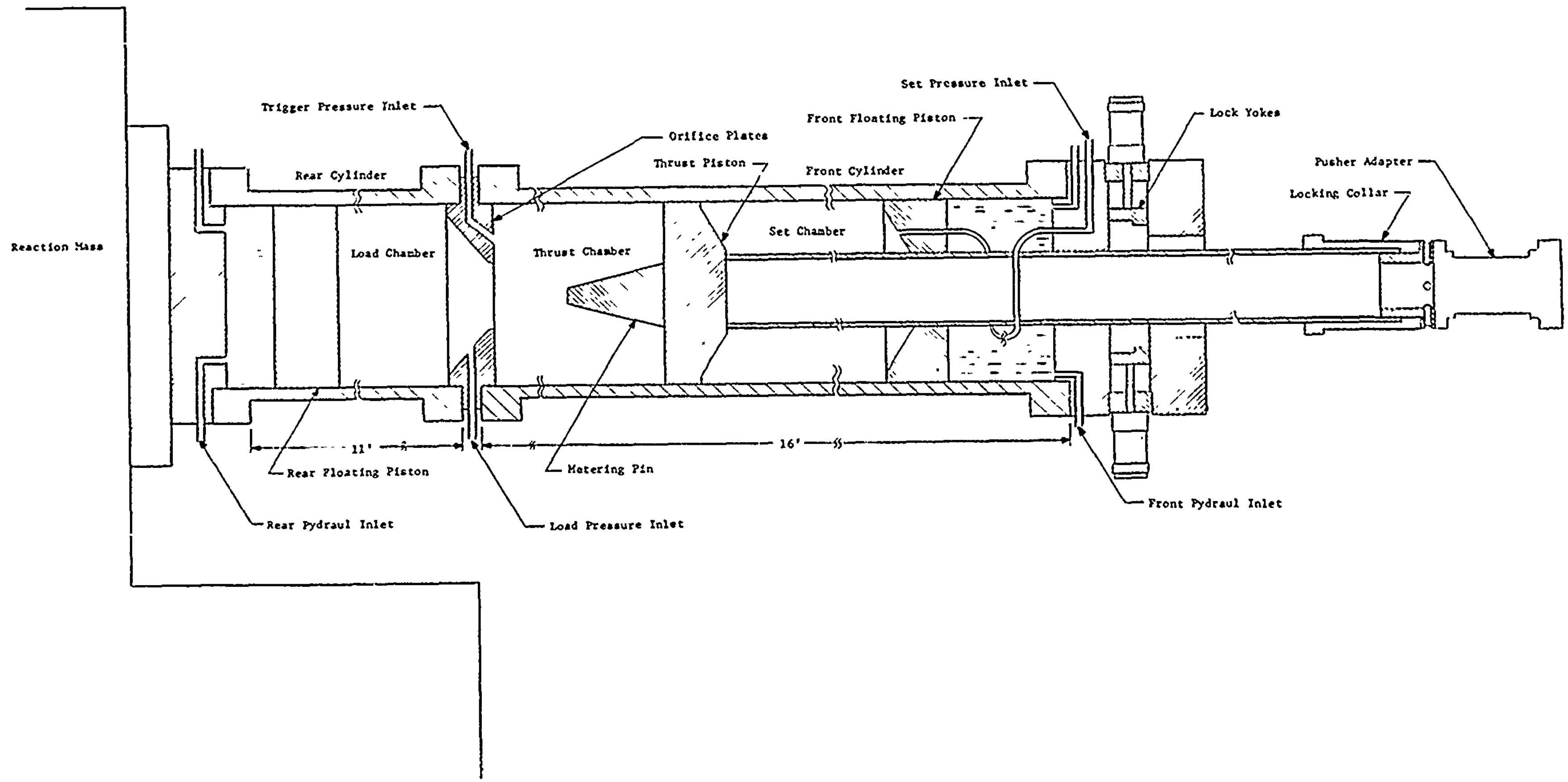


Figure 2 - CROSS SECTION OF HYGE ACTUATOR

The set pressure gas used is water-pumped nitrogen and is introduced through the front cover and transmitter via an internal hose connection to the set chamber. The load pressure gas used is compressed air, which is introduced directly into the load chamber through the orifice ring. The nitrogen and compressed air transfer systems will be described fully later.

The thrust column, thrust piston, metering pin assembly runs through the entire length of the front cylinder and is terminated outside the cylinder with an adapter mechanism which pushes the impact sled. The tubular thrust column is made from AISI 4340 steel and has an outside diameter of 10 inches. At the forward end of the thrust column is an assembly providing a locking collar that mates with the lock yokes to provide a positive safety latch in case of a seal failure.

The rear cylinder is terminated by a cover plate that bolts directly to the actuator reaction mass. The reaction mass weighs approximately 1,361,000 pounds with nominal dimensions of 20 x 29 x 17. The front cylinder is supported on a disassembly dolly to aid in moving the front cylinder away from the rear when servicing is required in the orifice area. The overall length of the actuator assembly, from the reaction mass attachment to the end of the pusher adapter, is 368.55 inches.

Values that can be used for calculation or setup purposes are given in Table 1 along with effective chamber areas and maximum pressures.

Because of the various internal members such as floating pistons, end caps, thrust column and thrust piston, the maximum realiziable load and set volumes differ from those given.

TABLE 1 - HYGE ACTUATOR PHYSICAL PROPERTIES

	LOAD CHAMBER	THRUST CHAMBER	SET CHAMBER
Maximum Length	10 feet	11.8 feet	14 feet
Maximum Pressure	3,000 psig	5,000 psig(Surge)	5,000 psig (Surge)
Net Area	50 sq in.	452 sq in.	374 sq in.

The thrust chamber as listed here exists only during the after firing. Any length accumulated by it is at the expense of the set chamber length. The maximum value listed is only an estimate of the maximum attainable dynamic forward motion of the piston. As the thrust chamber was at one time part of the set chamber the maximum pressure is identical. The pressure listed for the set chamber is the peak surge pressure allowed during thrust column deceleration. The peak initial pressure recommended is 500 psig. The area given for the load chamber is the orifice area through which all load gas must pass to be effective against the full thrust piston area in the thrust chamber. The set chamber area is the full inside area minus the area of the thrust column. These area figures yield thrust piston area ratios (set/load or set/thrust) of 7.48 prior to firing and 0.83 during the acceleration pulse. The two things these figures say are that, at least theoretically,

the pressure in the load chamber may be 7.48 times the pressure in the set chamber without causing an autofire and a pressure in the thrust chamber of .83 times the set chamber pressure will cause the thrust column to move forward. In practice it has been found that due to the friction of the thrust column and sled the autofire pressure ratio is approximately 8.3 and the thrust chamber pressure must nearly equal the set chamber pressure to cause motion.

SLED DETAILS

The test sled provides the mounting platform for test articles. Figure 3 shows top and bottom views of the sled with its basic components and structure. The top mounting surface is nominally 4' x 6'. Tapped 5/8" - 11 specimen mounting holes are provided in the pattern indicated. The sled weighs approximately 2,000 pounds and is designed to carry a nominal payload weight of 2,500 pounds. Higher payloads can be carried at reduced g levels and with consideration of allowable track reactions. The sled has a natural frequency much higher than the frequencies produced by the HYGE actuator. Because of this, impact profiles produced by the actuator may be considered to be transmitted to the base of the test article unaltered. Test articles may be attached to the top mounting surface by virtually any convenient method. The basic limitation is imposed by the allowable reactions to 20,000 pounds at each sled corner on the rails. A good design approach is to place the test article center of gravity in the sled center and as low as possible.

The sled is guided along the track rails by four Delrin reaction guides located at the corners of the sled. The side-to-side clearance is small enough so that no appreciable off-axis acceleration is imposed during the sled motion.

The sled guides along the rail surfaces on either Delrin sliders or asbestoes brakes. The 12 Delrin sliders provide the lowest post test deceleration level and are typically used when the resulting sled kinetic energy is below approximately 50,000 ft-lb. Above this energy level additional braking force is needed to stop the sled before the track ends. This additional force is provided by asbestoes brakes. These are nitrogen operated caliper brakes which provide increased drag force by pressure on the track rail surfaces. One-hundred forty-seven square inches of brake area are available. Four hundred pounds per square inch is the maximum pressure used in the braking system. This provides a normal force of 58,800 pounds or a drag force of 41,160 pounds using a coefficient of friction for asbestoes on steel of 0.7. This is enough force to dissipate 4,116,000 ft-lb of kinetic energy in 100 feet. Unless a very heavy payload is encountered or a very short stopping distance required this should be more than adequate for stopping the sled. If more force is needed, the brake pressures may be increased up to 1,875 pounds with care.

The sled brakes are divided into two independent systems. One system operates the brakes contained in the corner housings and the other operates the brakes in the center housings. The corner housings contain a total of 16 brake pads and the center housings contain 14. The Delrin sliders used

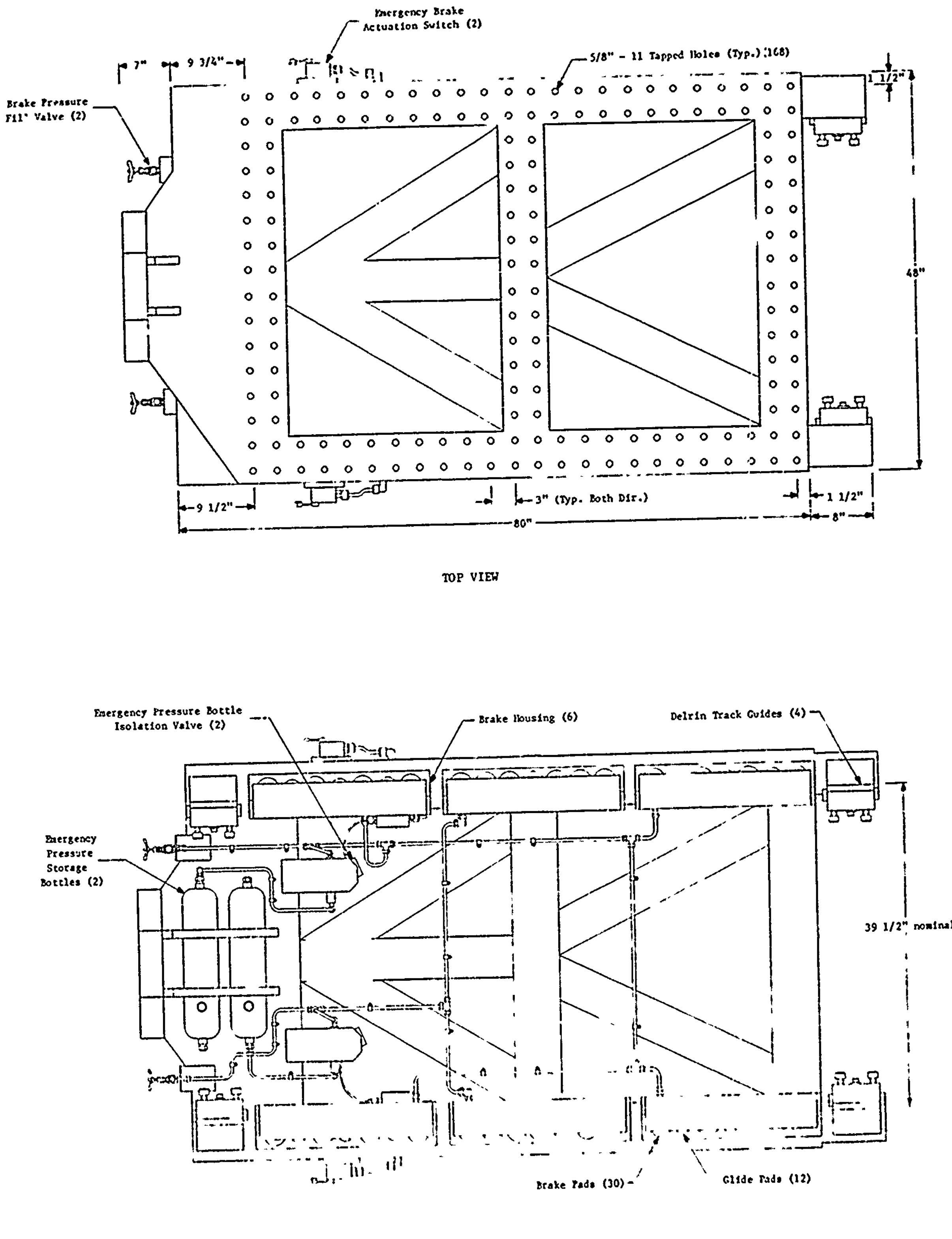


Figure 3 - SPECIMEN MOUNTING SLED

for low energy shots are contained in the corner housings. The two independent systems are provided as a safety feature so that loss of pressure in one system will not result in a complete loss of braking force. Each of the brake systems also has an isolated compressed nitrogen bottle incorporated into it. These isolated bottles are used as emergency brake pressure reservoirs. If the sled should travel beyond some predetermined distance due to one of the primary brake systems failing or a miscalculation of the required drag force, the additional gas is dumped into the brakes providing increased stopping power and preventing the sled from crashing into the end of the track. Should, for some reason, both brake systems fail and both emergency bottles fail, a crushable metal honeycomb pad is installed at the track end to minimize damage to the sled and test article.

This arrangement of primary braking system and backup bottles also provides two methods for stopping the sled. In most operations where supplemental brakes are required, the brakes are applied prior to the test impact and immediately begin decelerating the sled after the impact. Firing the sled with brakes on in this fashion does not appreciably effect the sled pulse. The backup bottles in this mode are an emergency system only. Should it be desired to maintain a low acceleration level after the pulse is over, it is possible to use the pressurized bottles as the primary braking system. The sled would be fired with no brake pressure and riding on the Delrin sliders. After traveling a selected distance down the track, the gas in the bottles would be dumped into the brake systems to stop the sled. Operation in this manner is still quite safe and reliable as the two independent systems are maintained. The bottle dump valves are so configured that activation of either system will cause both bottles to be dumped.

TRACK DETAILS

The facility track provides the gliding surface for the sled. The track rails are made of AISI 1020 mild steel and are 1-inch thick. The track is 240 feet in length. The rails are installed in 10 foot sections. The first 30 feet of the rail system incorporate high-strength anchor bolts to provide a load supporting capability of 20,000 pounds at each sled corner resulting from reactions of eccentric sled loads.

Figure 4 shows a cross section of the track and its foundation. The inside guide surfaces are 39.50 inches apart. The total cross-sectional area of the track foundation is 21.47 square feet. The moment of inertia is approximately 5×10^5 inch ^{4} about the centroid. The centroid is located 1.61 feet above the bottom of the foundation. The centerline of the track rail is located 2 inches above the top of the foundation and the centerline of the thrust column/sled combination is nominally 4 1/4 inches above the track centerline. There is about an eighth of an inch increase in the sled height when the sled brakes are actuated. The thrust column centerline, due to installation variances, is approximately 1/16 of an inch East of the track center when the actuator is properly aligned.

PERFORMANCE

The performance of the Impulse Accelerator that has been determined by testing at the time of this writing is outlined in Table 2.

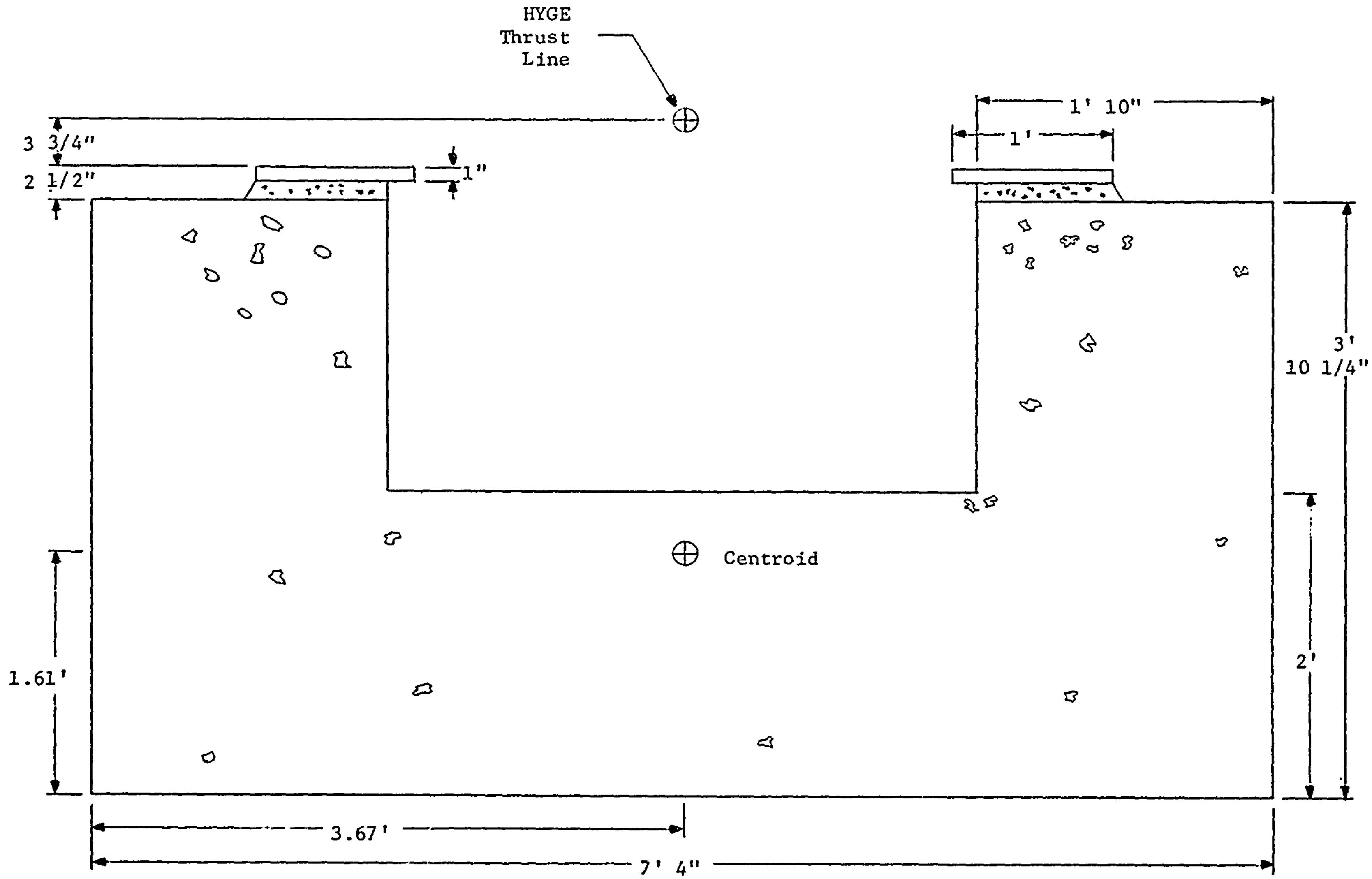


Figure 4 - CROSS-SECTION OF T- -K FOUNDATION

TABLE 2 - DEMONSTRATED PERFORMANCE AND PHYSICAL CHARACTERISTICS

Payload (lbs)	0	500	2000
Max Acceleration (G)	83	104	115
Max Pulse Duration (sec)	0.160	0.165	0.175
Max Velocity (ft/sec)	146	169	158
Sled size (ft)	4 x 8		
Track Length (ft)	240		
Max Stroke (ft)	8.4		
Max Dynamic Force (lbs)	750,000		
Reproducibility %	± 2		

The figures are intended as a rough guide only and are based upon testing which has been done to date. The actual performance limits will depend upon what pulse shape is being utilized and, to a certain degree, the dynamics of the test article. In addition, the peak g, maximum velocity and maximum stroke cannot be achieved simultaneously. Appendix III gives more detailed performance charts and sample acceleration profiles.

The two basic pulse shapes that the HYGE can produce at the time of this writing are a sine wave and a trapezoidal wave. These shapes are produced by using appropriate metering pins in the orifice. In practice, the waveforms are not pure but variations that are highly dependent on stroke lengths and pressures. The sine waves produced are variable in shape from rise times greater than fall times to fall times greater than rise times. The trapezoidal wave shape is generally trapezoidal but only under certain conditions. Again Appendix III shows the variations that may be encountered. Other types of pulses may be produced by using other metering pin shapes. At the present time only two pins are available.

In terms of the peak g and velocity attained by the HYGE the pulse shapes are very repeatable. It is very easy to achieve ± 2% reproduction from test to test with careful setup. As 2% is usually not required and on the order of the measurement accuracy, normal operating procedures are such that only 5% reproducibility should be expected. Higher variations than this should be cause for suspecting a system malfunction or operating error.

SUPPORT SYSTEMS

The HYGE requires three major support systems for operation. A hydraulic fluid pumping system is used for changing stroke lengths and load volumes. A nitrogen transfer system supplies gas for the set chamber for operating the sled brakes. Finally, an air compressor provides the high pressure gas used for propulsion and triggering. Each of these systems will be discussed in turn.

The hydraulic fluid reservoirs and pumps are shown in Figure 5. Independent systems are used for the front and rear cylinders. The lengths of the load chamber and set chamber are changed by pumping hydraulic fluid out of or into the cylinders through the inlets shown in Figure 2. The hydraulic fluid used is Pydraul A200B manufactured by Monsanto. Each system is a completely enclosed system. This means that the position of the floating pistons inside the actuator may be determined by observing the amount of fluid left in the reservoirs. Because of the presence of the thrust column in the front cylinder the relation between feet of movement of the pistons and change in level of the reservoir is different for each cylinder. In the rear cylinder a change of 1 inch in the level of the reservoir corresponds to a change of 2.25 inches in the position of the rear floating piston. Scales on the reservoir sight glasses are calibrated to read directly in feet of load and set chamber length. Hydraulic fluid is introduced into the cylinders by using the pumps between the reservoirs. It is removed by using air pressure in the chambers to force the fluid out and back into the reservoirs. Detailed procedures for accomplishing these functions will be found in Appendix II and in Reference 1. In practice, the set chamber piston position may easily be determined by noting the position of the thrust column during the pumping operation.

The nitrogen transfer system is shown in Figure 6. The bank of bottles is divided into two sections. Either one or both may be used depending upon the set chamber volume and pressure requirements. Water-pumped nitrogen is introduced into the set chamber through the control center to the nitrogen inlet in the front cylinder cover (Figure 2). In addition to filling the set chamber, nitrogen is used to operate the lockyoke actuators and sled braking system. Seventy-five psig nitrogen is supplied to the lock yokes through a pressure regulator in the control console. Brake pressure is supplied through a detachable hose to the sled. Both the emergency bottles and the primary brake pressures are set through this hose.

The air compressor used to provide the high pressure air for propulsion and triggering is shown in Figure 7. It is a Norwalk Type TR-55T, horizontal five stage tandem compressor for oil lubricated air service. The compressor has a V-belt drive, is water cooled and delivers 107 scfm at approximately 86^{o} F. The maximum pressure capability is 3,500 psig. It uses a 60 hp, 440 V electric motor for drive and runs at 350 RPM. An across-the-line starter is used and may be actuated from either the HYGE control panel or the compressor room. A valve is contained in the water line which automatically provides cooling water when the compressor is started. Normally open solenoid valves are provided to blow down the first two stages when the compressor is shut down. This permits a restart without having to manually blow down these stages in the compressor room. Further details may be found in Reference 5.

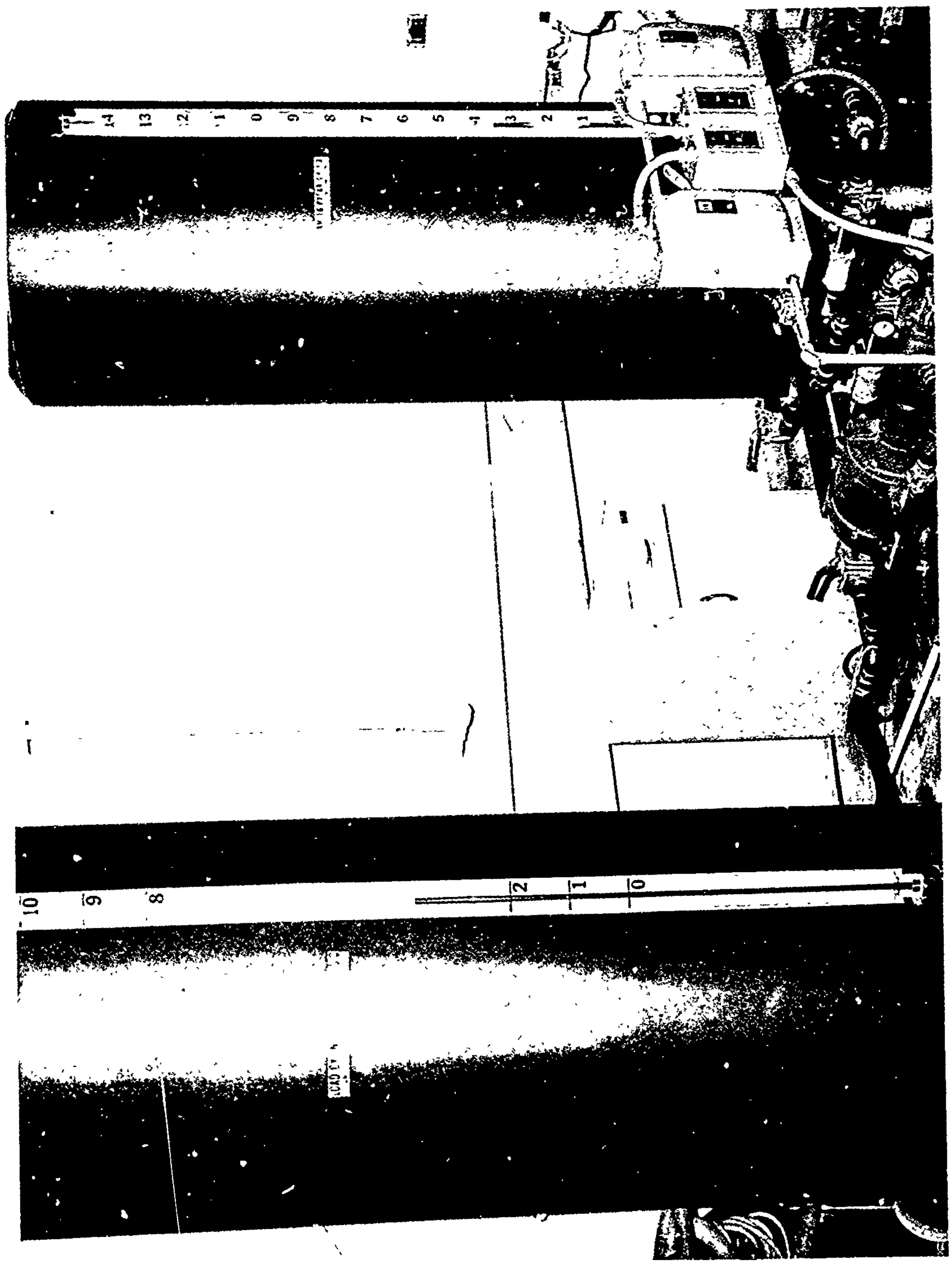


Figure 5 - PYDRAUL TRANSFER SYSTEM

Figure 6 - NITROGEN TRANSFER SYSTEM

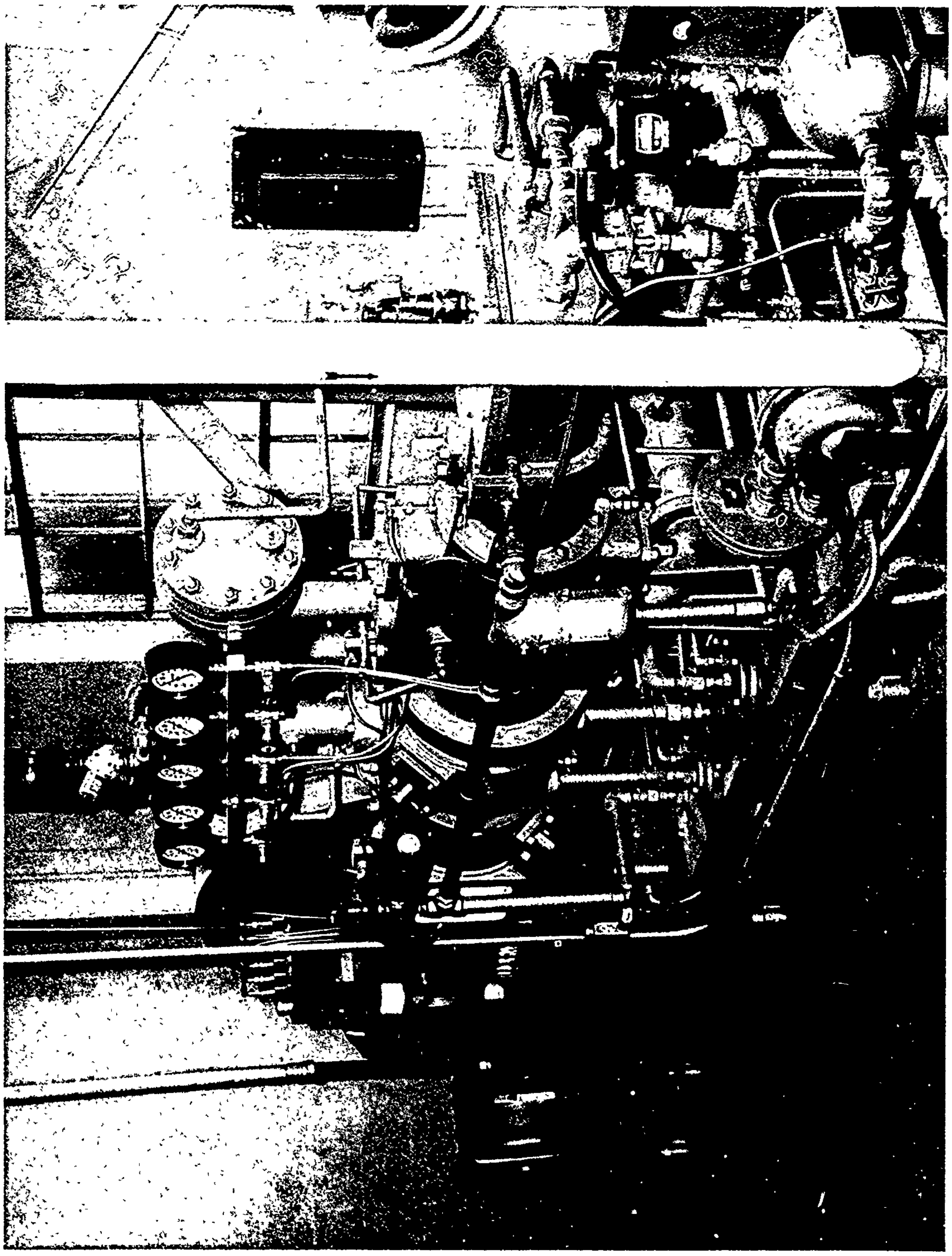


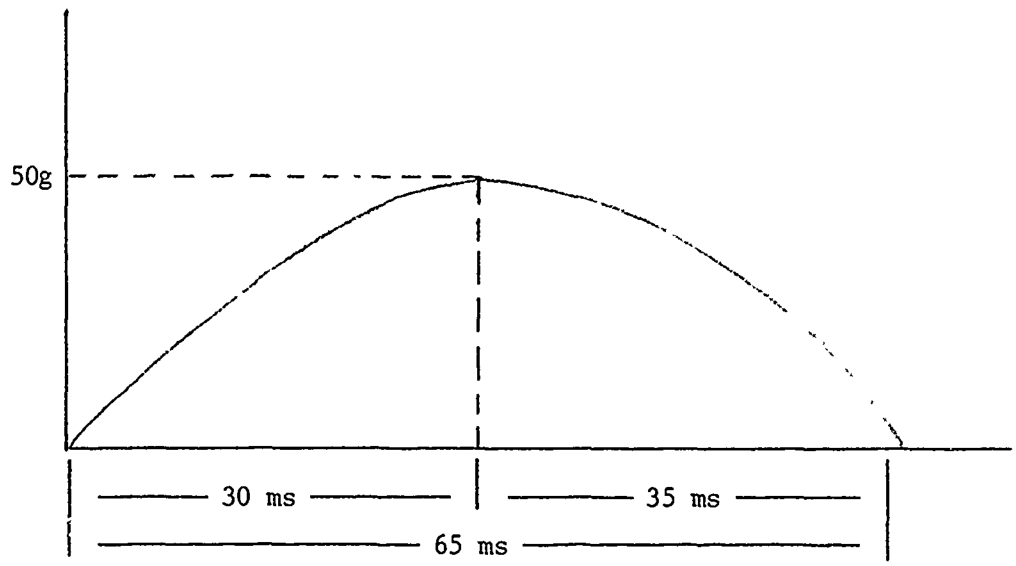
Figure 7 - NORWALK AIR COMPRESSOR

SAMPLE TEST SETUP CALCULATION

The following is a sample of the procedure used for calculating the pressures and volumes to be used for a given test profile. It is patterned after the method suggested in Reference 1. The resulting setup parameters will give only a rough idea of the setup to be used. The HYGE should be test fired using the derived parameters, and, based upon the results, further tuning performed until the pulse meets specifications. The charts in Appendix III are needed to estimate the setup parameters.

SAMPLE PROBLEM

Determine the required Set Pressure, Load Pressure, Gas Volumes and Brake Pressure to obtain the acceleration time curve shown below. The test specimen weight is 2,000 pounds and a stopping distance of 70 feet is required.



SOLUTION

a. Calculate Displacement

From Reference 1 the equation for the theoretical displacement in feet is:

$$X = \frac{2A}{\pi}\left[t_r^{\,2} - \frac{2t_r^{\,2}}{\pi} + t_r t_f + \frac{2t_f^{\,2}}{\pi}\right]$$

From the given conditions

$A = 50g \times 32.2 = 1{,}610\ \text{ft/sec}^2$
$t_r = 0.030$ seconds
$t_f = 0.035$ seconds

$$x = \frac{(2)(1610)}{\pi}\left[(.030)^2 - \frac{(2)(.030)^2}{\pi} + (.030)(.035) + \frac{(2)(.035)^2}{\pi}\right]$$

$$x = 1{,}025\,[.0009 - .00057 + .00105 + .00078]$$
$$= 1{,}025\,[.00216] = 2.214 \text{ feet} = 26.57 \text{ inches}$$

b. Set Pressure Volume Length = $\frac{26.57}{.6}$ = 44.3 inches

NOTE: 0.6 is an empirical value which represents the approximate proportion of the set volume length which is effective in producing acceleration

c. Load Pressure Volume Length = 3.5 feet = 42 inches

NOTE: This figure is selected from the table below which recommends initial load volume lengths based upon the set volume length. Use of this table will minimize the surge pressure reaction in the set chamber which is limited to 5,000 psig.

SET VOLUME LENGTH	LOAD VOLUME LENGTH
0 to 5 feet	3.5 feet
5 to 7 feet	5.0 feet
7 to 10 feet	7.0 feet
10 to 14 feet	10.0 feet

d. Determine Set Pressure

Refer to chart 6 in Appendix III. At 50 g's, the Set Pressure is 190 psig.

NOTE: As chart 6 is for a 60 ms half sine pulse the set volume length corresponding to 190 psig is only 35 inches. Use of 190 psig set pressure with a 44.3 inch set volume length will result in a lower g level than is required. This problem should be resolved when test firings are made.

If the test specimen weight is significantly different than that shown, the set pressure determined should be scaled according to the following equation.

$$P_{s_{Req'd}} = \left(\frac{W_{sled} + W_{int.\ parts} + W_{specimen}}{W_{sled} + W_{int.\ parts} + 2020} \right) P_{s_{with\ 2020\#\ specimen}}$$

W_{sled} + 2000#

$W_{int.\ parts}$ + 1950#

e. Determine Load Pressure

Load Pressure = (Set Pressure)(6) = 1140 psig.

NOTE: The LOAD/SET pressure ratio of 6 is a typically used maximum value. It may of course be lowered. Chart 11 shows the effect of doing this. Basically lowering the pressure ratio will lower the g and velocity. Since we already expect the g to be too low from d, the maximum is used here.

f. Calculate the maximum velocity

From reference 1, the velocity may be calculated from the equation:

$$V = .01398\ A\ t_t$$

Where V = Velocity in MPH
A = Acceleration in G's
t_t = Total pulse time in milliseconds

Hence:

$$V = (.01398)(50)(65) = 45.4 \text{ MPH}$$

g. Determine Kinetic Energy of Sled

$$\text{K.E.} = (.0335)\ (W_{sled} + W_{specimen})\ V^2 \qquad \text{(Reference 1)}$$

$$= (.0335)(2000 + 2000)(45.4)^2$$

$$= 276{,}195 \text{ ft-lb}$$

h. Determine Brake Pressure

From Graph 12, an effective brake pressure of 25 psig is required to to stop the sled in 70 ft. The total Brake pressure required is then

$$P_{B_1} = 25 + \frac{2000 + 2000}{147} = 52 \text{ psig}$$

The final set of test parameters which should be used for the initial testing is then:

a. Set Volume Length = 44.3 inches
b. Load Volume Length = 42.0 inches
c. Set Pressure = 190 psig
d. Load Pressure = 1140 psig
e. Brake Pressure = 52 psig

The surge pressure should be monitored during setup testing. This value is limited to 5000 psig. It should be no problem for this particular condition. However, for high pressure and/or very short stroke impacts it would be wise to start at low pressures and gradually work up to the test conditions. Trigger pressure is normally held at 200 psig.

THEORETICAL CONSIDERATIONS

Obviously, the set of curves in Appendix III does not describe adequately setup parameters for all tests which may be conducted. Furthermore, the equations just used to estimate the test parameters are valid only for the sine wave pin. The trapezoidal wave pin will yield different results.

To test and produce charts for all possible combinations of parameters would require tremendous amounts of work. A far better way is to develop an understanding of how changes in setup parameters effect the pulses and to only use charts to "ballpark" the solutions. The HYGE system could also be modeled and test parameters determined analytically. This has been done and the equations which govern the motion are given in Appendix I. In many cases though it is still simpler to empirically set up the test. Some of the general effects of parameter changes are noted below and can be used for deciding how to change parameters. The effects listed are only general and it must be remembered that a large amount of interaction can occur. Experience in this area is the best teacher.

The parameters which effect the impact profile are:

1. Set Pressure
2. Load Pressure
3. Set Volume Length
4. Load Volume Length
5. Specimen Weight
6. Set/Load Pressure Ratio
7. Pin Shape

Gas temperature, trigger pressure and sled brakes have only small effects on the impact pulses and for all practical purposes can be ignored.

PARAMETER CHANGE	RESULTANT EFFECT ON IMPACT PULSE
a. Increased Set and Load Pressures	Increase G Decrease Rise Time Slightly Decrease Total Time Increase Velocity
b. Increased Set Volume Length	Nearly Constant G Increase Velocity Increase Time
c. Increased Load Volume Length	Increase G Increase Velocity Increase Time – small change

PARAMETER CHANGE	RESULTANT EFFECT ON IMPACT PULSE
d. Increase Specimen Weight	Decrease G Decrease Velocity Increase Time Increase Rise Time (slightly)
e. Decrease Set/Load Pressure Ratio	Decrease G Decrease Velocity Decrease Time
f. Change from half sine pin to Trapezoidal wave pin	Decrease G Decrease Velocity Increase Time

INSTRUMENTATION SYSTEM

SYSTEM ENVIRONMENTAL DATA

With a facility such as the Impulse Accelerator, its ultimate usefulness is determined by the abilities incorporated within it to measure both the test environment and the test article responses. Accurate analysis can only be accomplished when meaningful, accurate data is collected. Because the facility has a wide range of uses, from equipment survival tests to human subject responses, the data collection equipment must be both versatile and accurate. This section describes the system environmental measurements that are made to describe the impact profile and to monitor the HYGE actuator pressures.

Four types of pressure measurements must be made on the HYGE actuator to insure accurate test pulses and reproducibility. They are load pressure, set/surge pressures, brake pressures and trigger pressure. Many of these pressures are required as part of the system operational controls and are automatically monitored by the control system. The control system will be described later.

Two separate measures are made of load pressure. The primary measure is made by a Bell and Howell 4-394-0001, 0-3500 psi strain gage pressure transducer installed in the orifice ring transducer outlet. The output is displayed digitally in psi units on the operator's console. In addition, a 0-3000 psi, 720° Heige bourdon tube pressure gauge on the operator's console is teed off the load pressure fill line. This gauge is used primarily as a check for the orifice installed transducer.

The set pressure transducers serve two functions. They monitor the initial set up pressure and the dynamic surge pressure. Because of the large difference between the magnitudes of these pressures, separate measuring systems are used. The primary transducer for measuring pretest set pressure is a 0-500 psi Bell & Howell 4-349-0001 strain gage pressure transducer. Its output is displayed digitally in psi units on the operator's console. A 0-600 psi, 720° Heise bourdon tube gauge is also available on the operator's console providing a backup measurement. Both of these pressure measuring devices are located in the operator's console. This is required because they must be protected from the high surge pressure. Protection is provided by a set pressure isolation valve and a gauge protector. The surge pressure is measured by a 0-5000 psi Teledyne 176 strain gage transducer mounted on the front of the HYGE actuator. Outputs from this transducer are typically monitored only during setup testing and are recorded and displayed in the instrumentation room.

Two types of pressure measurements are required to monitor brake pressures also. A 0-500 psi Bell & Howell 4-394-0001 transducer is provided on the sled in the brake pressure lines on each of the two braking systems. These measure the primary braking pressure and the outputs are displayed digitally on the operator's console. Displays are available for both the center and corner brake systems. In addition, a Cook Electric 716-1001 pressure switch is provided on each emergency bottle. Pressure in the bottles must be at

least 400 psig to trip these switches. The output is used in the control system circuitry. The brake pressures can also be monitored during setup through the loading hose by a 0-600 psi Heise gauge on the operator's console. This measure is lost when the brake hose is disconnected prior to firing. The other measurements are maintained as their outputs are routed to the control circuits and console displays through the whip cable.

The trigger pressure is monitored by a 0-3000 psi Heige gauge in the operator's console. In addition, a Cook Electric 716-1001 pressure switch is used to insure that at least 80 psi is present for firing. Normally, a pressure of 200 psi is used to fire the sled.

In addition to the pressure measurements used for facility setup and control several measuring systems are used to record and display the impact test profile after firing. The primary system is a specially designed Velocity, Time, Distance System (VTD) (Reference 4). This provides, immediately after the test, digital readout of the peak g attained, the terminal velocity, pulse duration and accelerated stroke. The peak g is determined from an ENDEVCO 2262C, 200 g piezoresistive accelerometer mounted on the actuator ram. The velocity is determined from the peak output of a tach-generator mounted on the sled with a wheel running on the track surface. The pulse duration is determined electronically by measuring the time the accelerometer signal exceeds zero. (In practice, the time measurement starts when the acceleration exceeds 0.4 g). The accelerated stroke is determined by photoelectrically counting the passage of holes in the tach-generator drive wheel. The pulse distance is related to the number of holes which pass a photoelectric cell during the pulse.

In addition to the VTD measures, two accelerometers are provided on the test sled to measure the test environment. They are designated as the primary and secondary sled accelerometers. The sled primary accelerometer is an ENDEVCO 2260, 250 g piezoresistive accelerometer. The sled secondary accelerometer is a Statham A52, 150 g strain gage accelerometer. These accelerometer signals are recorded in the instrumentation room. During data reduction, the test environment is measured and tabulated from the sled primary. The VTD system outputs and the sled secondary accelerometer are used as backup measures and checks.

All of these system environmental data, pressures and accelerations, are used on every test. They provide the information necessary to setup the facility, operate the firing controls and measure the impact environment produced. The other data required are related to the particular test being conducted. As there are no fixed sets of requirements for this type data, the instrumentation can only be described in general. The basics of this part of the instrumentation are described in the next few sections.

DATA TYPES

The Impulse Accelerator instrumentation system is configured to handle primarily bridge type transducers. Included in this class are wire wound strain gage and piezoresistive crystal types. These types are commonly found in transducers which measure accelerations, forces and pressures.

The basic transducer channel is configured as a seven wire system. This type conditioning system allows accurate excitation voltages to be applied and calibration resistors which compensate for line losses to be inserted. Figure 8 shows a typical transducer channel data flow. Separate cables are used for excitation and data signals in the whip cable. Fifty-one channels of data may be carried through the whip cable in this manner.

DATA TRANSMISSION

Data from the sled are transmitted into the instrumentation room via an eighty-five foot whip cable. The cable is stretched out along the track prior to firing and the sled travels along the track picking the cable up as it goes. The cable slides along the bottom of the track stopping due to its own inertia. The signal wires are covered by a cloth jacket to protect them from abrasion.

DATA CONDITIONING

Prior to recording and display the data signals pass through several stages of conditioning equipment. Typically the transducer signals first enter the signal conditioners. Forty SRC Model 2545 signal conditioners are available for this purpose. These signal conditioners contain circuitry for producing the excitation voltages, inserting bridge completion resistors, balancing the bridge outputs and installing calibration resistors. An SRC Model 5108 calibration programmer is available for switching through the calibration resistors on all signal conditioners under either manual or automatic control.

Upon exiting the signal conditioners, the low-level, differential data signals are fed into Newport Model 70 amplifiers. Forty-eight amplifiers are available. These amplifiers serve two functions. First, they amplify the signal from the millivolt range of the signal conditioner output to the higher voltage range usually required by data recording and display equipment. Second, variable filters on the output stage of the amplifiers serve to bandlimit the data. In this installation, the data is bandlimited to 3,000 Hertz at this point. Data as it exits the amplifier stage is no long differential but single ended and ready to be fed into any of the various types of recording, display or analysis equipment.

DATA DISPLAY AND RECORDING

In general, all data after proper conditioning, are recorded and stored on analog tape. An Ampex 2000, 14 channel recorder is used for this purpose. The recorder is configured to provide 8 channels of the FM recorded data and 6 channels of multiplexed Direct recorded data. Each Direct channel is capable of handling 7 data signals. The total recording capacity than is 50 channels. The characteristics of the FM recorded and Direct multiplexed data will differ only slightly. The recorder is configured to record at a tape speed of 60 inches per second. For the FM intermediate band data (center frequency = 108 KHz) this results in a record/reproduce frequency fidelity of 20 KHz. However, due to the filters used in the previous amplifier stage, this is effectively 3 KHz. For the Direct multiplexed channels, filters on

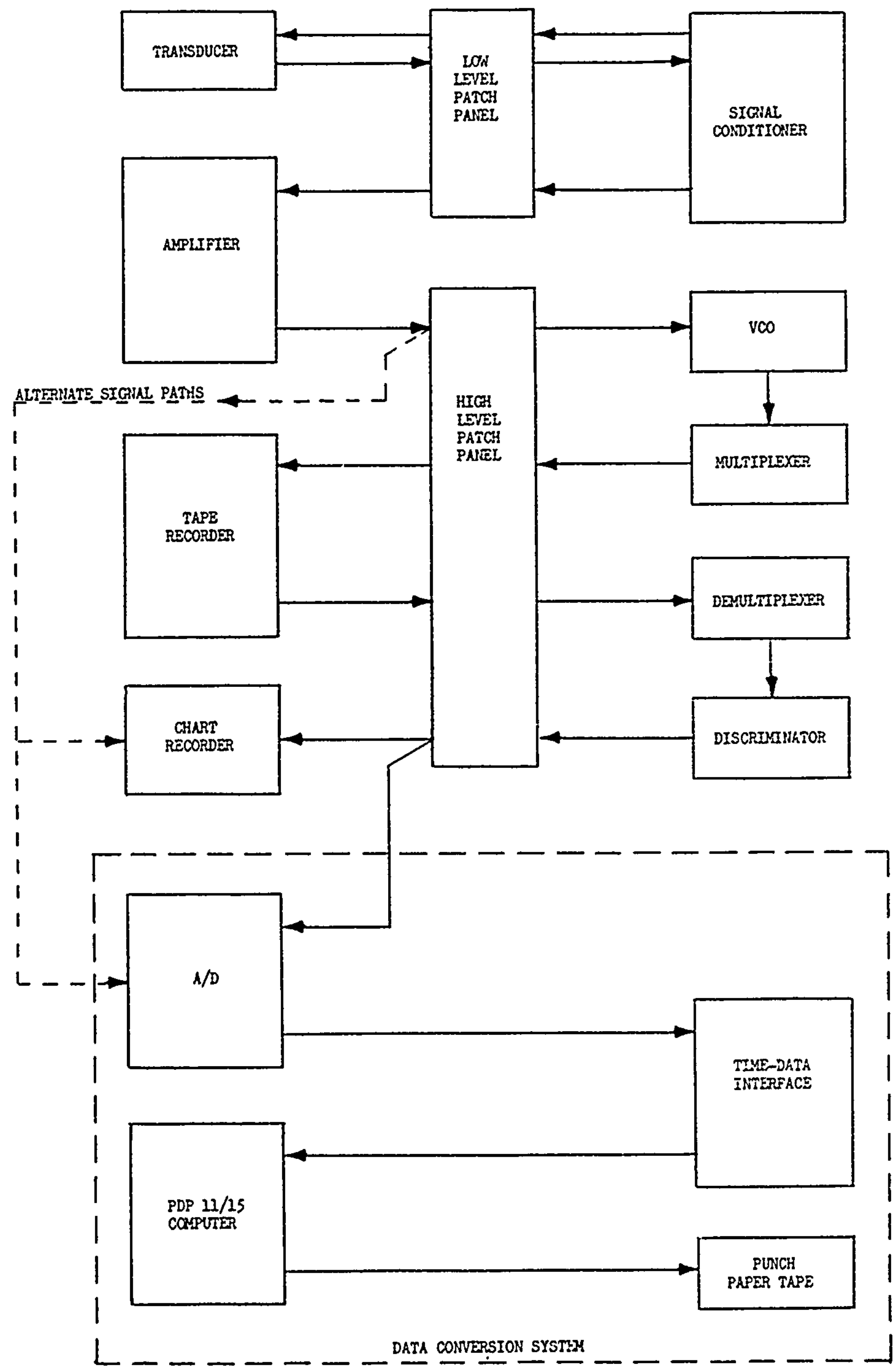


FIGURE 8 - TYPICAL TRANSDUCER CHANNEL

23 JAN. 75	INSTRUMENTATION SYSTEM
DR. S. ROHRER	TYPICAL CHANNEL SIGNAL PATH
ENG.	

the output of the descriminators limit the frequency content of the signal to 2.5 KHz. This will result in a slight phase shift between FM and Direct channels at high frequencies. As most of the data reduction is conducted at considerably lower frequencies, the phase shift differences will be negligible.

Data is also displayed in real time on the VTD system as discussed previously. In addition, an 18 channel oscillograph may be used to display up to 18 channels in real time. The oscillograph is use is a Honeywell Model 1858. This is a fiber-optic CRT recorder with a frequency response range of DC-5000 Hertz.

TIMING CONTROL

A timing control system is provided as part of the data acquisition system to allow time correlation of the electronic and photometric data. Control is provided by the camera station of the automatic control system. As it is normally used, timing pulses are admitted to the film records and tape recorder simultaneously at t=0 on the countdown clock. The timing source is selectable between an Astrodata Model5400 Time Code Translator/Generator and the AC line frequency. It takes approximately 80 ms after t=0 and admission of the timing pulses to the recording systems for the sled to fire.

PHOTO SYSTEMS

HIGH SPEED 16MM CAMERAS

The photo recording system is capable of controlling up to 8 high speed cameras; 5 off-board and 3 on-board. The cameras currently in use are Milliken DBM 55 and DBM 5B (AC powered) off-board and DBM 4B and DBM 44 on-board (DC powered). With these particular cameras, the film speed is limited to 500 frames per second. Higher speed cameras can be easily adapted for use by changing the control cabling.

Timing pips are placed on the film using a L.M. Dearing Model 2-3-3R Light Emitting Diode Driver. The pip frequency is controlled by the timing control unit discussed previously.

HIGH SPEED VIDEO RECORDING

High-speed video-taped records of the impact are provided by a Video Logic Corporation Instar System. The system consists of dual high speed, shuttered, video cameras and a video-tape recorder. The system captures a picture every 1/120th of a second at an exposure time equivalent to 2,000 frames per second. This usually provides 10 to 12 pictures during the impact event. Use of this system provides the capability to visually review the impact event immediately after the test as no processing is required.

HIGH INTENSITY LIGHTING

The high-speed cameras require supplemental lighting for recording the impact event. This is provided by two banks of Berkey Cine-Queen Model 112-035 lamps. Ninety-six lamps are provided with provisions for eight additional lamps. Control is provided for thirteen Berkey Colortran Converters. Each converter operates 8 lights. This lighting system can provide up to a maximum of 100,000 watts of power to the lights.

Operation of the lights is controlled automatically by the camera and lighting station. Because of the large power surge which would be required to activate all the converters at one time, the converters are activated sequentially. This minimizes the power surge and large line transients. It requires approximately 3 seconds to complete activation of all the lights.

SAFETY AND CONTROL SYSTEMS

AUTOMATIC CONTROL

The safety and control systems are a custom designed group tailored to meet the stringent requirements of human impact testing on the Impulse Accelerator. We have already looked at the basics of the operational systems in use on the facility. This section will describe the control functions and logic established to provide a high degree of confidence that the impact event will be conducted at the proper impact level under conditions of optimum safety for both the test subject and operating personnel with a reasonable guarantee that the required test data will be collected.

The original installation provided by Bendix contained the necessary circuits to fire the HYGE in a reasonably safe mode. These circuits are used in the automatic system and, in some types of tests, are still used for firing the sled. However, a human impact test is a unique situation requiring exact judgments to be made by operating personnel. To aid in these judgments the safety and control system are designed to provide a disciplined approach to the test by demanding the proper operational sequences be followed. A failure to follow correct procedures will cause the test firing to be aborted. The guiding philosophy behind the design of the control circuitry was that it should reinforce human judgment rather than subvert it.

The various control stations will be described in the paragraphs which follow. The stations will be described from the station operator's viewpoint. References 2 and 3 will provide further and additional information on the specifics of the control system.

The safety and control systems are a group of eight interconnected units which execute the logic sequence established to fire the sled under automatic control. The eight stations are:

1. Operator
2. Safety
3. Observer
4. Master Clock and Instrumentation
5. Data Analysis
6. Sled
7. Camera, Lighting and Timing
8. Medical Monitor

As a minimum, for particular types of tests or specific desires, five of these stations are required to successfully conduct a test. The ones which are capable of being bypassed are the Observer, Data Analysis and Medical Monitor. Various functions within the other stations, as will be described, are also capable of being bypassed.

1. Operator's Station

The operator's station is comprised of three control chassis'. These

chassis' are seen in Figure 9. The two chassis on the left side are the original Bendix chassis and the one on the right the added chassis for the control system. The Bendix chassis provide the valves, controls and gauges for establishing the correct firing pressures.

The far left chassis is devoted to handling the nitrogen gas for the set pressure and brake pressures. Low pressure nitrogen for lock yoke operation is provided via an internal regulator and requires no operator action. The set pressure valve allows gas to be admitted to the set chamber. This can only be done when the lock yokes are engaged. An exception to this occurs when nitrogen must be vented during the setup mode. The set pressure is read on the Heise gauge and on the panel meter in the right hand control chassis. These readings will be accurate only under no flow conditions; that is, the valve must be closed for proper readings. The Heise gauge and panel meter should agree within five pounds or a malfunction or calibration problem should be suspected.

The emergency brake reservoirs and primary brake pressures are established in the left console section also. When the brake reservoir button is in the "fill" condition, gas can be introduced into the brake reservoirs. When adequate pressure is available, the reservoirs are isolated by pushing the button. From this point on, activation of the sled mounted limit switches or power loss will cause the reservoirs to open dumping the reserve pressure.

After the emergency pressure is established and isolated the brakes are bled down to the correct primary pressure for the test firing. This may be a large pressure or none at all, depending upon the test conditions and braking sequence selected.

The pressures are monitored by the small Heise gauge on the console and by the two panel meters in the control section. A separate display of each brake section is provided in the control section.

After the appropriate brake pressures have been established, the brake fill hose is removed from the sled and placed on the appropriate interlock switch next to the actuator. When the hose is removed from the sled, the Heise gauge loses its ability to monitor the brake pressures. The control section, however, maintains its display of primary brake pressure. Emergency pressure is monitored by the sled station and an indication is given on the safety station, both of which will be discussed shortly.

The HYGE actuator now contains the appropriate set pressure and the sled has the proper amount of brake pressure for firing. It is at this point the automatic operation begins to deviate from the manual. In manual operation, the "load vent" button would now be pushed closing the load vent valve, sealing the load chamber and allowing pressurization to begin. This button is not used in the automatic mode. Closing of the load vent valve is accomplished in the right side control section by turning on the key switch. In addition, this switch is only active after the safety station has declared an "ALL SAFE".

Assume for the moment that an "ALL SAFE" condition has been declared and

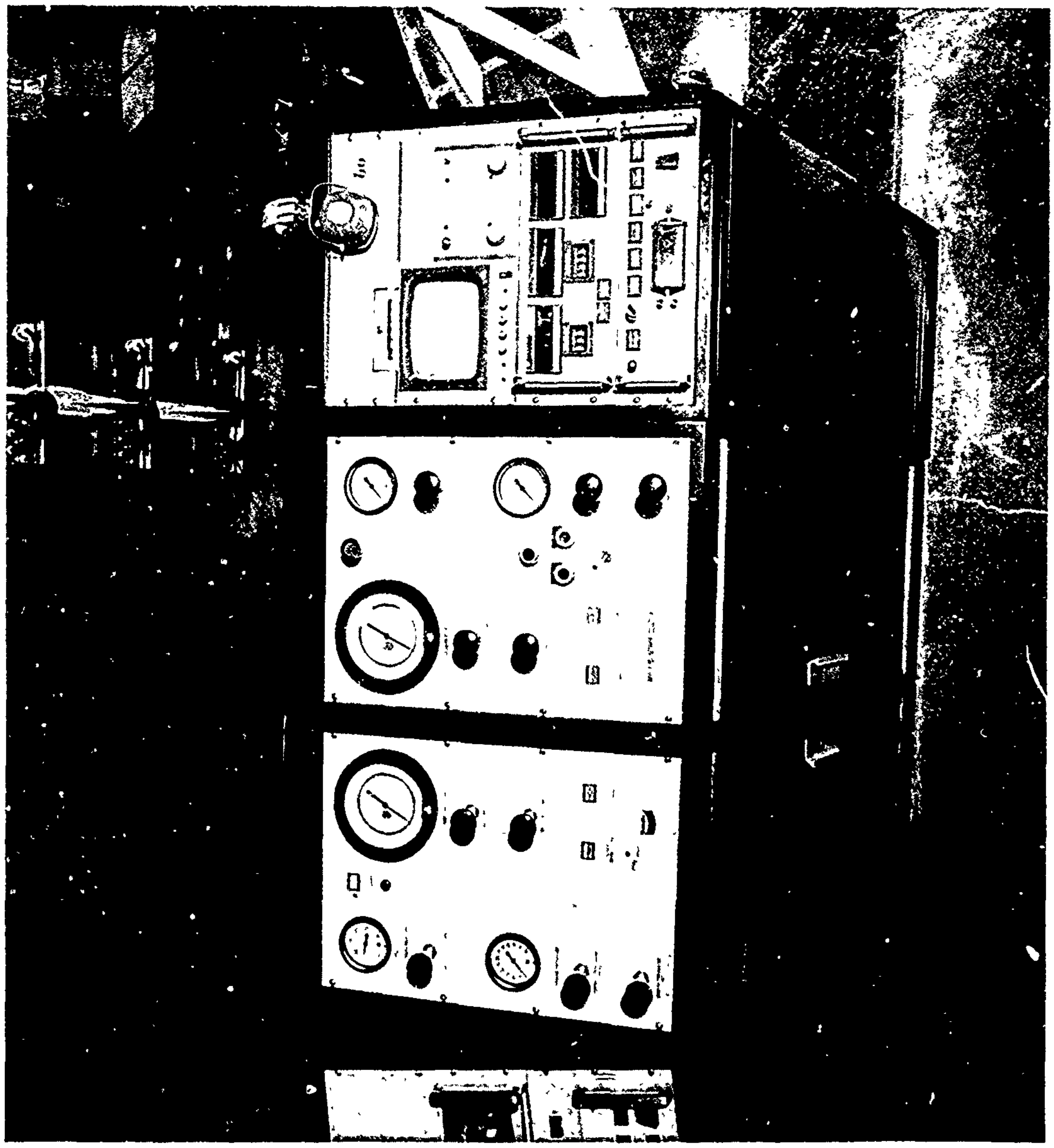


FIGURE 9 - OPERATOR'S STATION

the load vent has been closed. The operator's functions now shift to the center console. This console controls the air compressor which pressurizes the load chamber and trigger valve.

The compressor is started and stopped by the buttons near the center of the console. Trigger pressure is ordinarily established first through its fill valve. Typically a pressure of 200 psig is used. Its magnitude is read on the console Heise gauge. An indicator in the control section shows that the trigger pressure exceeds 90 psig.

Load pressure is introduced through the load valve. Its magnitude is read on the Heise gauge and on a panel meter in the control section. These pressures will also read accurately only under no flow conditions, although the panel meter reading will be very close because of the fact that the transducer is in the orifice ring. These two pressure readings should not differ by more than 10 psi.

Buttons are present in the load pressure section for actuating load yoke retraction and opening the trigger valve. These buttons are not functional during automatic operation. They are used in the manual mode. A key switch is also present in this section for selecting either the "MANUAL" or "AUTO" mode.

After the correct load and trigger pressures have been established, the HYGE is primed for firing. To complete the firing, the lock yokes must be retracted and the trigger valve opened. But before the operator can perform these functions, all other stations must be ready.

We now come to the control console of the operator's station. This console contains various switches, button and displays to allow the operator to monitor the status of the various systems and the HYGE pressures.

The console is broken down into three sections. The upper section contains communication and visual equipment. The center section contains the HYGE pressure monitoring equipment. The lower section monitors the other stations' status and contains the countdown clock controls and "FIRE ENABLE" switch.

The communications section contains a microphone speaker combination and a closed circuit television monitor. The microphone speaker allows the operator to communicate with the other stations and/or to use the PA system. Also included is a television monitor which allows the operator to, via a three camera net, see all areas of the track which may not be directly visible to him.

The pressure section first of all displays the pressures established during setup in the left hand control consoles. In addition, two indicator lights are present in this section. One indicates that trigger pressure is available or "LOADED". The other monitors the pressure levels within the set and load chambers. This indication is either in "SAFE" or "DANGER". The indicator must read "SAFE" before the load vent can be closed. To establish a "SAFE" condition the thumbwheel switches located under the set pressure and load pressure displays must be used. The switches under the set pressure display are set for the minimum set pressure. The set pressure

must be above this minimum. This provides an automatic indication that the set pressure is holding. The thumbwheel switches are ordinarily set 5 psi below the correct set pressure. The switches under the load pressure display are set for the maximum allowable load pressure. They are usually set approximately 30 psi above the required load pressure. In addition to these two measures, an internal ratio circuit monitors the actual load/set pressure ratio. The ratio is limited to 7 to 1, below the autofire pressure ratio. Should any of these three conditions be violated the indicator will change to "DANGER" and the load pressure vent automatically open. The vent will remain open until a safe condition is re-established.

The lower section of the operator's console provides the operational controls and allows the operator to monitor the condition of the other stations. Functionally, the operations occur left to right on the console. The first indicator on the far left displays the condition of the safety station. When this is green the key switch next to it may be activated, closing the load vent and the load cylinder may be pressurized. Before the operator can proceed in the firing sequence, the next three indicator lights must be green. The first of these is "SYSTEMS". For this to be green, a ready signal must have been given by the instrumentation station and the camera lighting and timing station. Next is the "MEDICAL" indicator. For this to be green, the medical monitor must have depressed his ready button. Should the test not require a medical monitor or should the button not be desired for use, a bypass plug is inserted in the medical station which maintains a "green" condition. The next indicator is the "SUBJECT". It operates similarly to the medical indicator but through the sled station. A bypass plug is inserted in the appropriate place at the sled station if a subject switch is not required.

If all lights on the console are green to this point, it indicates to the operator that all stations are ready for firing and the firing sequence may be initiated. To begin the firing sequence the operator pushes the button below the "ARM" light and starts the countdown clock. An arm condition indicates that power is available for activating the trigger valve. When the countdown clock has been started, the test proceeds automatically to firing. If any one of the monitored functions in various stations fails or goes out of acceptable range the countdown will go into a hold if the time is before T-10. After T-10 any status change will cause an "ABORT" to be registered and the load pressure will be dumped.

If the countdown is proceeding satisfactorily the lock yokes will automatically be retracted at T-5 and the lock yoke status light will change from green to yellow. At T-0 the HYGE will fire if all conditions are satisfactory and the hooded "FIRE ENABLE" switch is being held up by the operator. A similar switch is available on the safety station and must also be held up by the safety station operator.

These switches are spring loaded and if not activated or are released before T-0, they will cause a hang fire "ABORT". The load pressure will be dumped.

This completes the basic description of the firing sequence and requirements. The various stations which were mentioned as feeding signals to the operator will now be described in more detail.

2. Safety Station

The safety station and safety station operator are responsible for insuring that the area is secured and that various other safety related functions are operational. The safety station is shown in Figure 10. This is the first station which must indicate ready before firing can commence.

The upper portion of the safety station contains communications equipment similar to the operator's station but without the television monitor.

The small center section contains controls for manually operating the KLAXON. These are used in conjunction with the manual firing system and allows some of the safety functions to be maintained in this mode. Another switch in this section closes a drapery across the observation window should spectators need to be excluded from watching a sensitive test.

The bottom portion of the safety station is a series of lights and switches to permit the safety station operator to monitor various safety related functions. All of the indicators must be green before he can declare an all safe by pushing the "Pressurize Enable" button. Each of the functions monitored by the lights will be described in turn. A countdown clock is located in the upper center of the portion of the station which indicates where in the countdown the system is currently.

The first indicator light establishes that the brake pressure hose, retract cable and sled intercom are in the proper storage position and nct attached to the sled. The storage position is on the interlock switches next to the HYGE actuator.

The next indicator monitors the condition of the sled. For this light to be green, the emergency brake pressure bottles must contain more than 400 psi of nitrogen and a key switch on the sled station must have been turned on indicating that the test article is in the proper position for firing.

The "CONTACT" light indicates that the sled is in contact with the pusher ram. This light is actuated by a microswitch mounted on the rails beside the ram and is closed when the sled is in full contact.

The "DOORS" light and switch insures that all doors leading into the test area are closed and locked. When all doors are closed the light will show green. They may be locked by moving the switch to the lock position. In the upper right hand portion of the panel a small "area access" switch is located. This may be activated by the safety station operator after an all safe has been declared to permit entrance or exit to the area through selected doors if needed without losing an all safe condition.

Next is the "FENCE" indicator and switch. This contro's the light beam which surrounds the track. If someone should approach the sled or track after it has been activated by this switch, the light beam will be broken and the all safe lost. The fence light will show green when the transmitter, mirrors and receiver are properly aligned and the switch activated.

The next light indicates the status of the observer station to be described

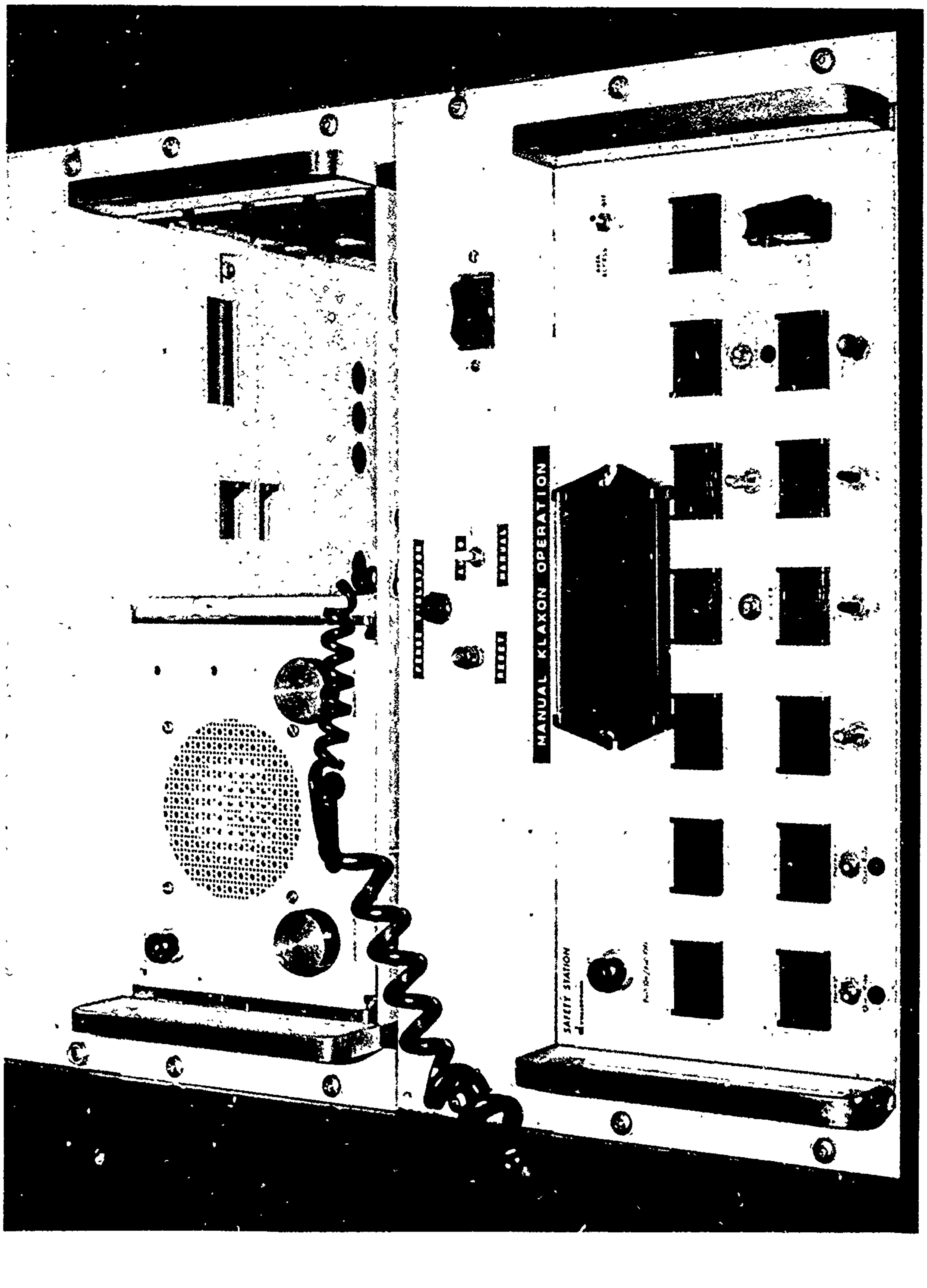


Figure 10 - SAFETY STATION

later. When this station is indicating ready, this light will be green. An override switch is provided for this station as many times an external observer is not required by the test.

The "ABORT" light merely indicates that a test abort has occurred. The indicators in the lower row begins with the "LOG" light and switch. In the normal position, all communications will be logged on a tape recorder in the instrumentation room. The tape recorder is activated by pressing the microphone button. An override position is available should this log not be required.

The next light is related to the proper operation of the P.A. system. This indicator may also be overridden if the function is not desired for monitoring.

The "INTERCOM" light is merely an indicator that the safety station operator has verified that communications are available to all required stations. It will be green when the switch is in the "checked" position.

The "KLAXON" indicator is used to check the operation of the warning horn. When the switch is in the "tested" position, a loss of an "all safe" condition by any means will cause the Klaxon to sound.

The "BEACON" light and switch indicate that the beacon lights have been checked for proper operation. The switch is placed in the "tested" position for firing. The beacon operates automatically based upon the conditions present in the firing system. The beacon lighting group is located on one of the supports for the lighting rack. It contains a red light, a green light and a rotating red beacon. This group will show a green light when the load vent is open and the lock yokes are engaged. A yellow light will be indicated when the lock yokes are retracted. The rotating red beacon indicates that the load vent valve is closed.

When all of the lights on the safety station panel show green and any previous abort has been cleared, the safety station operator may declare an all safe by pushing the red "Pressurize Enable" button. This allows the HYGE operator to close the load vent and proceed with the load chamber pressurization. A change in the status of any one of the indicators in this group will cause the all safe to be lost and the load vent to be automatically opened. The KLAXON horn will also sound.

The last switch on the safety station is the hooded "Fire Enable" switch. It operates exactly as the fire enable switch on the HYGE operator's console; that is, it must be held up at T-0 for a firing to occur.

3. Observer's Station

The observer's station operates as a satellite to the safety station. It is merely a go/no go switch and is physically similar to the medical station which will be seen later. It is used when the safety station operator requires assistance. Typically, this would be when a group of spectators are in the area to view a test. It can also provide the project director with an override switch should he desire one.

4. Master Clock and Instrumentation Station

The master clock and instrumentation station is located in the instrumentation room. It is shown in Figure 11. It is by far the most electrically complex of the various stations as it contains most of the controlling logic circuits. However, from the operator's viewpoint most of the functions are hidden and the front of it contains lights, switches and controls for operating the instrumentation and countdown sequence.

The upper row of lights and indicators are used to assist in the analysis of an abort should one occur. The appropriate LED above each of the eight status lights will light indicating the particular system which caused the abort.

Just below this row of lights are other switches and displays. Left to right are the power on/off switch, time source selector (internal or IRIG) and countdown display. Just next to the countdown display are indicators which tell whether the countdown has been started or is in a hold. These are indicators only. The countdown may not be initiated through this station, only at the HYGE operator's console.

Below the countdown display is a thumbwheel comparator switch which establishes the preset time for the countdown. When the reset button on the HYGE operator's console is pushed, the system clock is reset to the time indicated on the thumbwheel switch.

The lights and switches next to the preset switches indicate the status of the instrumentation systems and of the data analysis station. When the instrumentation systems operator is satisfied that all instrumentation is ready to collect data, the precount switch is moved from not ready to ready. The other light and switch indicates the status of the data analysis station. In the normal position a ready signal is required from the data analysis station before the precount light will go to green irregardless of the position of its switch. An override function is available to eliminate use of the data analysis station should it not be required. In any case, because on line data analysis is not considered critical, a failure of this station will not cause a fire abort. The data has been stored on tape and can be processed later if necessary.

The bottom row of the instrumentation station contains four comparators for automatically operating various pieces of instrumentation. These comparators currently operate the chart recorder (oscillograph), magnetic tape recorder, calibration actuator and the drop tower facility. This last comparator is involved with the control system of the Vertical Drop Tower and is not involved in the Impulse Accelerator Control. The switch above it will be in the override position when the Impulse Accelerator is in use. The times indicated on the comparator thumbsheel switches are the respective start and stop times in use for each of the pieces of equipment. The vertical row of three lights next to each comparator indicates the current status of the equipment. Should any one of the controlled devices fail to start or operate, an abort would be initiated, assuming, of course, that the override switches are in the normal position. Along the very bottom of the station are switches and buttons which allow the various devices to be operated independent of the

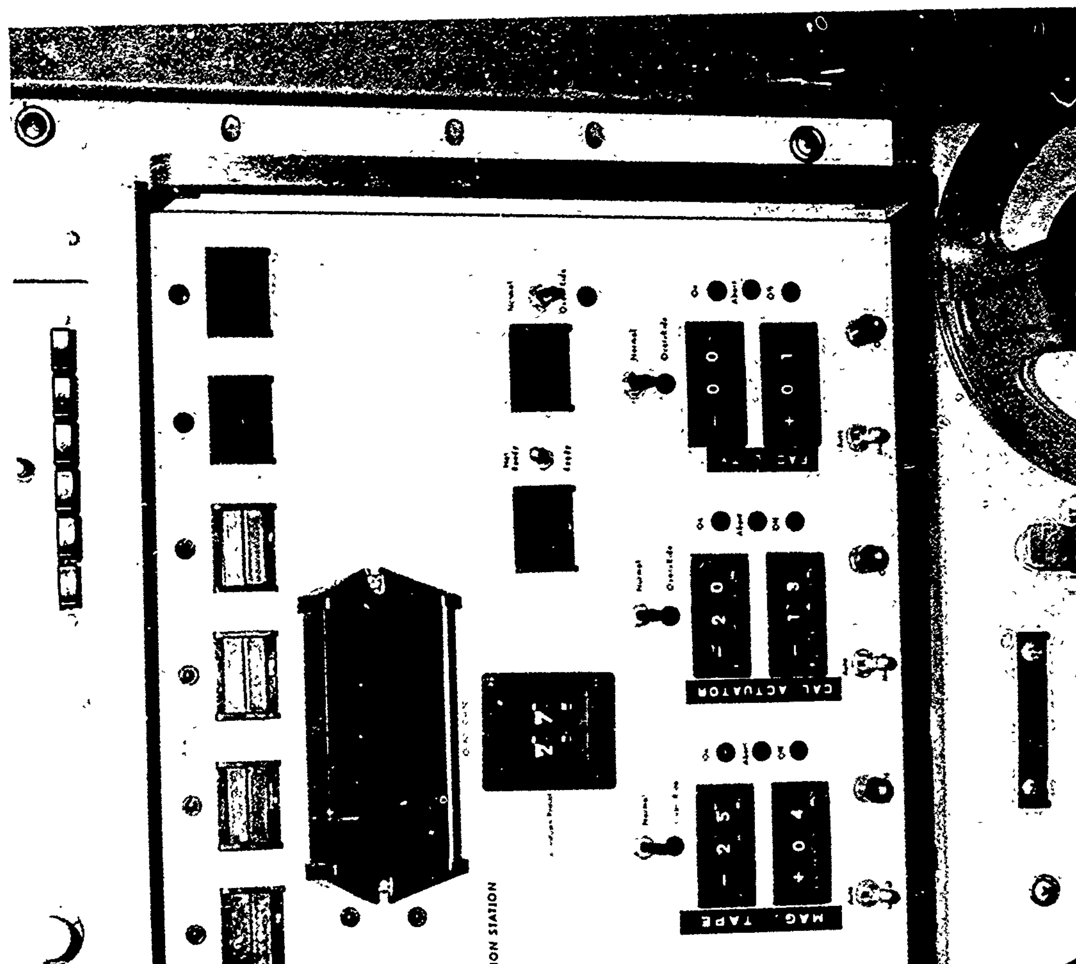


Figure 11 - MASTER CLOCK AND INSTRUMENTATION STATION

automatic countdown times. These are used for setup and checking.

5. Data Analysis Station

There are times when it is desired to collect and process data in real time with the impact event. The required data signals are patched to the data analysis area through the instrumentation system console. The data analysis station, shown in Figure 12, provides start and stop time pulses to the data analysis equipment being used. This station operates as a satellite to the instrumentation station. Collection and processing of real time data by this station is considered non-critical to the Impulse Accelerator operation and it has no abort capability. Start and Stop time pulses are provided at the times indicated on the thumbwheel switches. A display is also given of the current countdown time. Four types of pulses are provided by this station. At the START time a one second pulse is generated. At the STOP time another one second pulse is generated. During the START-STOP Intervel a level shift is provided. A 1/sec time pulse is provided continuously.

6. Sled Station

The sled station shown in Figure 13 provides information to two other stations. The upper portion provides the information necessary to obtain a green sled condition at the safety station. Specifically, it provides an indication that emergency brake pressure is available and that the sled is in a ready condition (Key on). The subject is able to see that these conditions are present. The lower portion of this station provides the subject with an abort switch. When this switch is depressed, a ready condition is indicated at the HYGE operator's console. A bypass plug is required if the subject switch is not used. In the center of this station is a small LED display. This display indicates the last ten seconds of the countdown.

7. Camera, Lighting and Timing Station

The Camera, lighting and timing station is shown in Figure 14. This station provides the comparator controls for operating the high-intensity lights, the off-board or fixed cameras, the on-board cameras and the timing synchronization system. The upper portion of the station contains the camera LED driver circuits. The lower section contains a countdown clock display, comparator thumbwheel switches, abort indicators, override switches, manual control switches and a precount ready switch. The precount switch together with the precount switch in the instrumentation station provide the required signals for a "SYSTEMS" green on the HYGE operator's console.

The function of the comparators, override switches and manual control switches is the same as those in the instrumentation station. An abort signal from this station will cause a firing abort.

The auxiliary comparator group provides the timing synchronization for the photo and electronic data. At the time indicated the timing pulses are admitted to the camera LED's and to the tape recorder.

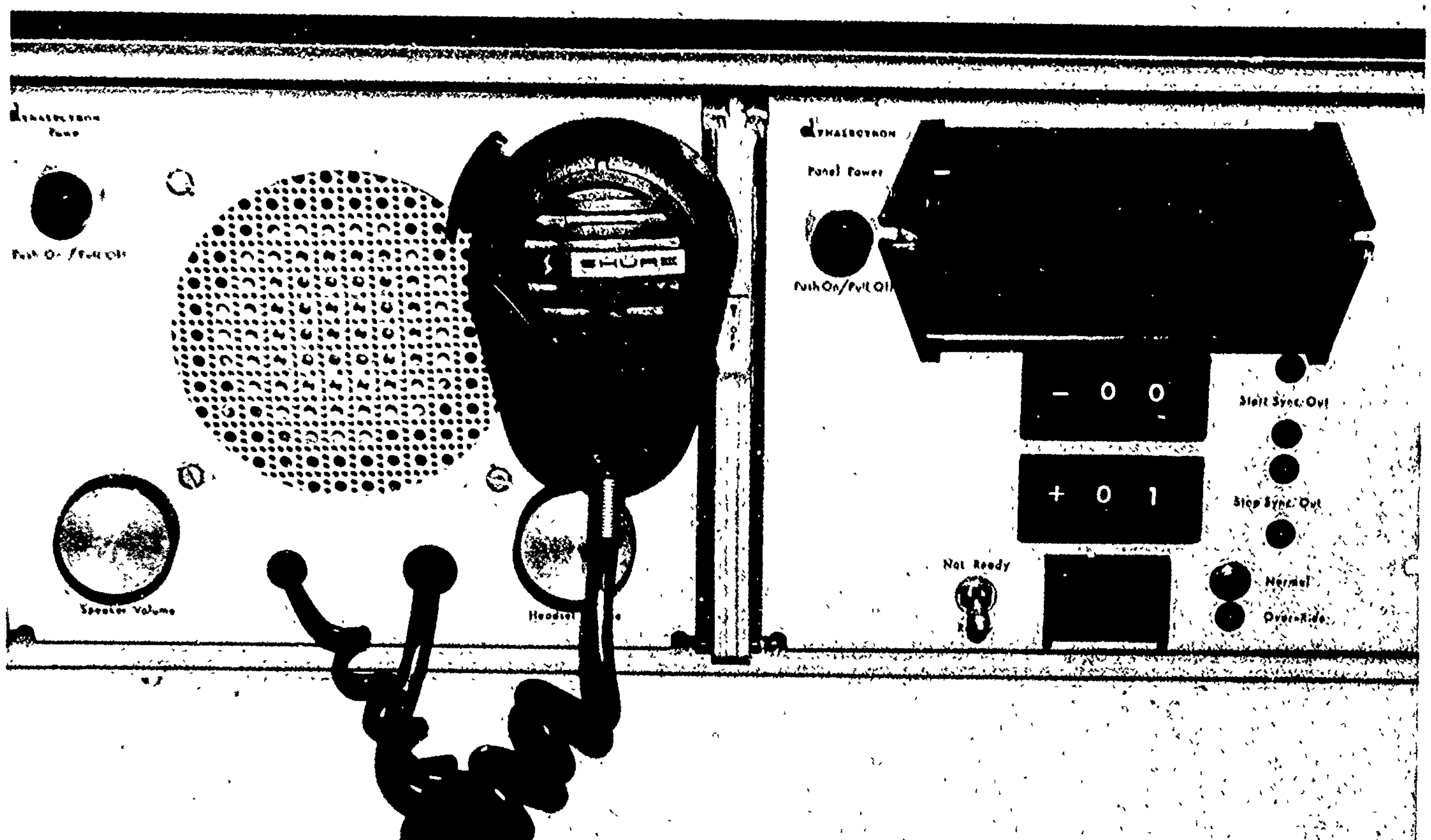


Figure 12 - DATA ANALYSIS STATION

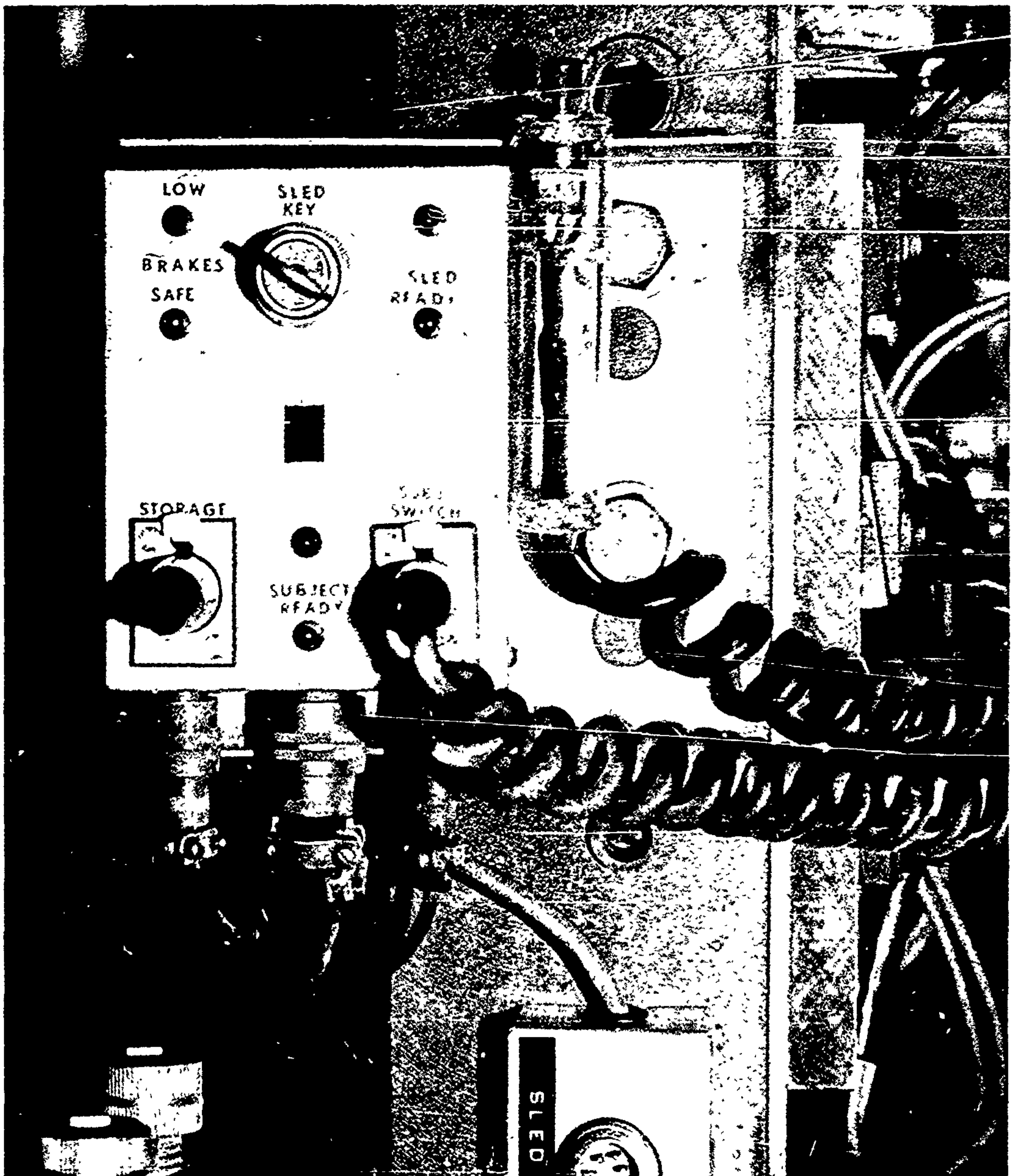


Figure 13 - SLED STATION

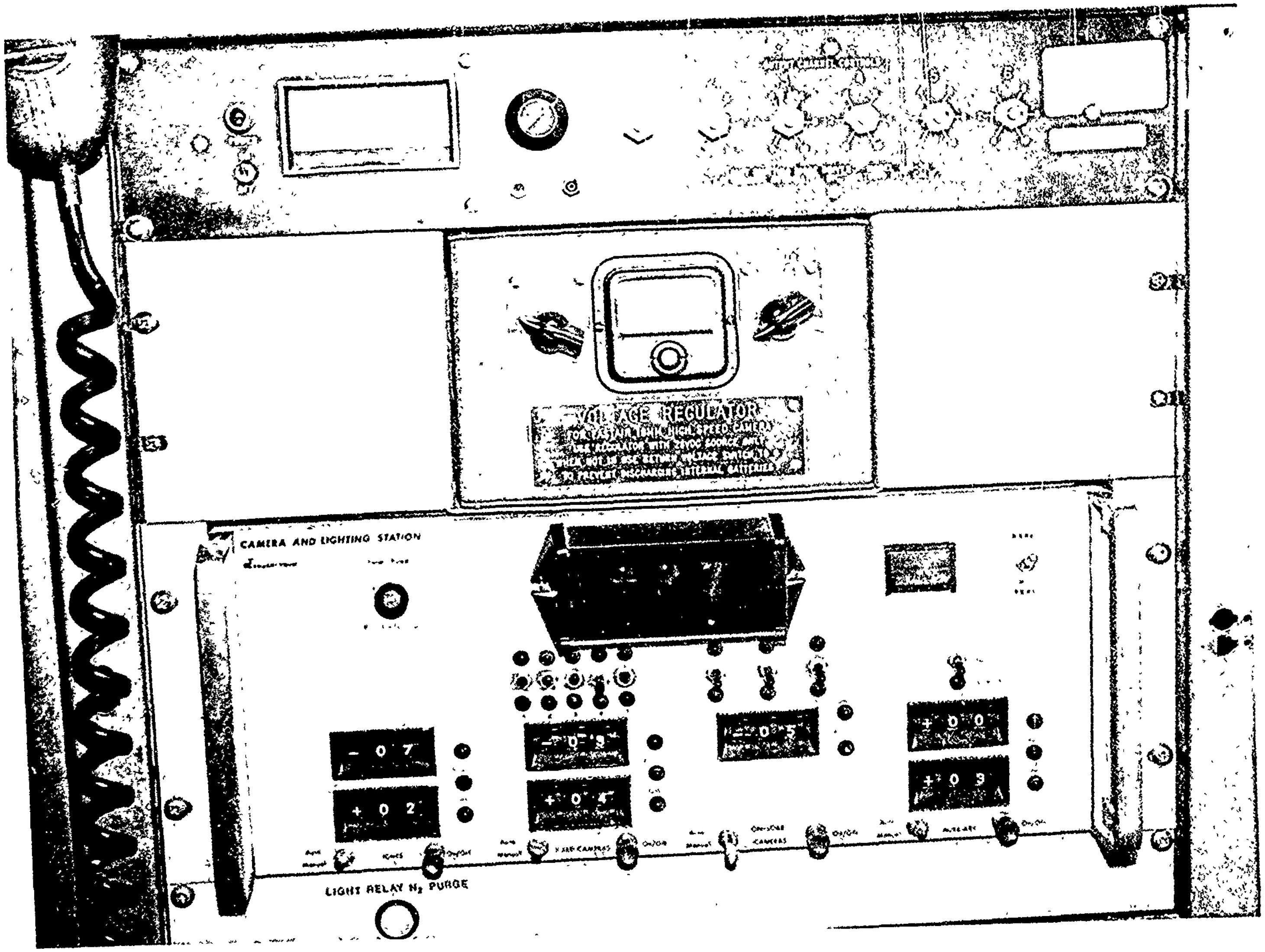


Figure 14 - CAMERA, LIGHTING AND TIMING STATION

8. Medical Monitor Station

The medical monitor station, Figure 15, provides the medical monitor with a visual countdown display and an abort button if he should desire it. The position of the abort button is indicated on the HYGE operator's console. If the abort button is not used, a bypass plug is required. This station is identical to the observer station except that its function may not be overridden except with the bypass plug.

MANUAL FIRING AND SETUP MODE

The manual firing mode was the method for firing the HYGE actuator prior to installation of the automatic system. The first human test program was conducted under manual control.

As mentioned previously, the HYGE actuator is still capable of being fired using the basic Bendix control system. Refer to Reference I for an outline of these procedures. The one additional action necessary to fire the HYGE manually is that the "FIRE ENABLE" switch on the operator's console must be held up in the fire position. It is recommended, however, that this mode only be used with the utmost caution on the part of the operator.

The manual mode is now used exclusively for setting up the HYGE actuator with the proper volumes for firing. The procedures used to change volumes violate many of the conditions established for automatic firing. Changing of volumes should only be performed by someone thoroughly familiar with the controls and piping arrangements for the HYGE actuator. A checklist for changing volumes is provided in Appendix II.

AUTOFIRE

A little used, but legitimate, method of firing the HYGE is the autofire mode. It can be accomplished only in the manual operational mode. In this mode the lock yokes are retracted early in the sequence and the load cylinder pressurized until the pressure-area difference is overcome and the actuator autofires. An advantage of this method is that it allows pressure ratios of approximately 8.3 to be developed and can have significant effects on the pulse shape. However, the exact time of firing cannot be predicted. This makes data collection extremely difficult. The mode is not recommended except as a final resort and then not for human testing.

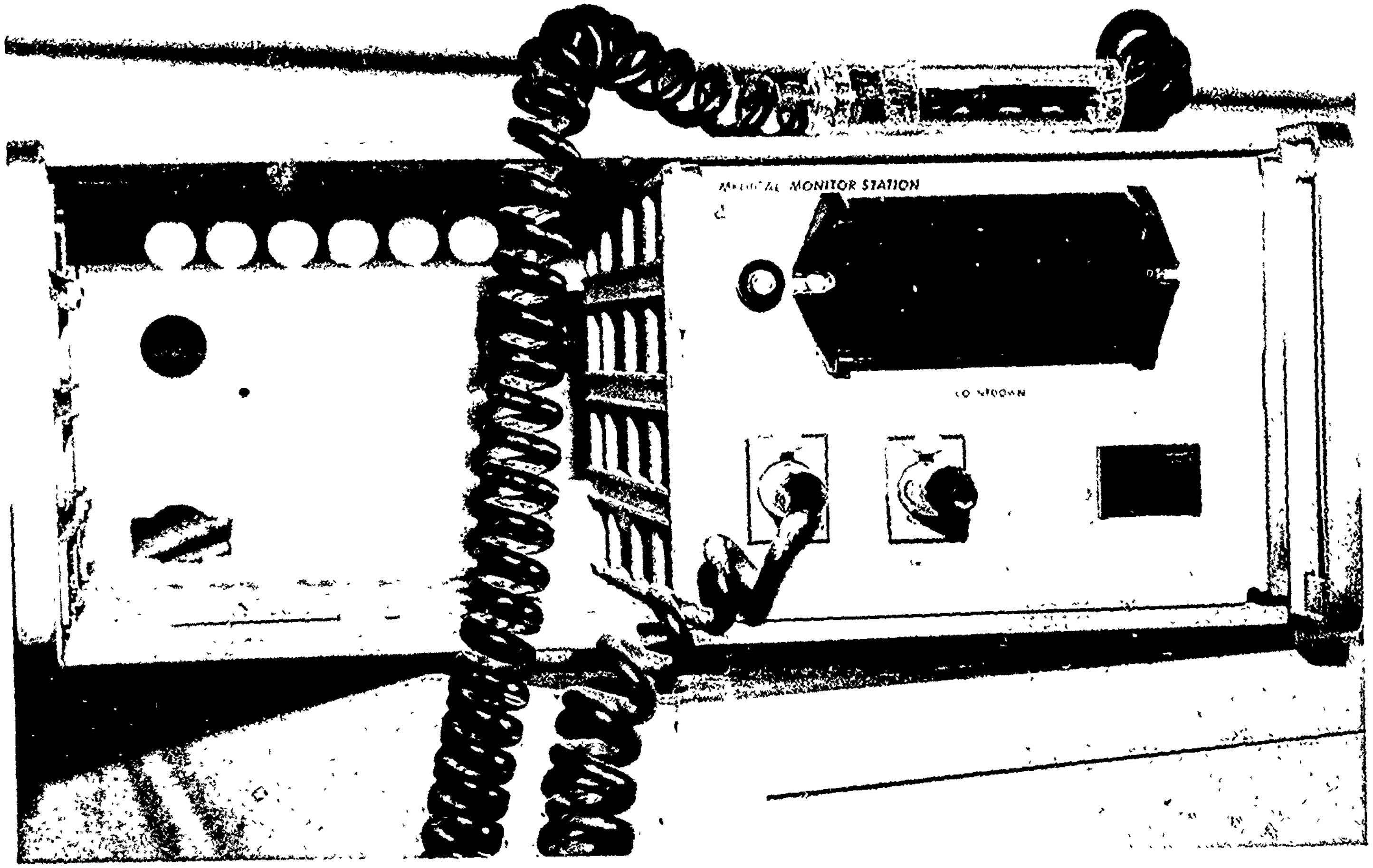


Figure 15 - MEDICAL MONITOR STATION

DATA REDUCTION SYSTEMS

REQUIREMENTS

The purpose of data reduction is simply to reduce collected data in a manner which brings out or highlights specific characteristics of interest in a test. The final use of the information usually determines the method or technique to be used. This may require data to be reduced quickly to allow decisions on test progression to be made or may require complex, longer term evaluations of responses. The data reduction systems associated with the Impulse Accelerator Facility attempt to provide capabilities in both areas. As the requirements change considerably with the test program, this section will describe the general types of equipment available with the Facility.

QUICK LOOK

Quick look data is usually required on all programs to ascertain that expected data is being collected and that expected trends are being achieved. The information will sometimes differ test to test, but usually involves examination of analog waveforms for peak values and shape and visual observation of recorded photo data.

The Honeywell oscillograph is used to record analog traces from a test. This may be done real time with the test or by playback immediately after the test is completed. For most tests a complete set of oscillograph records can be produced 10 to 15 minutes after a test. The records contain the timing marks introduced at T=0 to permit correlation between records.

Information on the impact pulse is provided by the Velocity, Times, Displacement system discussed previously in the Instrumentation Section of this report. This system gives direct readout of peak g attained, terminal velocity, pulse duration and accelerated displacement.

Videotape replay is provided by the Instar system also described in the Instrumentation section. The test can be replayed in real time, slow motion or stop action. The system provides enough detail to avoid having to wait for high-speed film to be processed and may even take the place of high-speed cameras on certain tests.

These various techniques usually provide all the information required for quick review. Detailed analysis such as Vector summations, special purpose integrals, or model response to the measured data require more lengthy processing.

RECORDED ANALOG DATA

Processing of data recorded on analog tape may require many different types of techniques to be used. The equipment available for use attempts to anticipate these techniques and allow reductions to be made as easily as possible. This equipment will be described in general as to the types of processing which they are capable of performing.

A very useful piece of data reduction equipment is the Time/Data 1923/30 Time Series Analysis System. It is a computer based (DEC PDP 11/15) system. It processes analog data directly from the tape recorder. The two major software programs currently in use with the system and their computational abilities are listed as follows:

1. 1923-0217 Panel 30 Software Program

    a. A/D conversions up to 50,000 Samples/sec channel (2 channels).
    b. Fourier Transforms up to 50 KHz.
    c. Auto Spectrums up to 50 KHz.
    d. Transfer Functions up to 50 KHz.
    e. Auto Correlations.
    f. Cross Correlations.
    g. Amplitude Histograms.
    h. Waveform Averaging.

2. 1923-0239 Shock Response Spectrum Analysis

    a. Damped Shock Spectrums.
    b. Single Degree of Freedom Model Responses.

The system operating manual will provide complete details of the capabilities of the system. This piece of equipment is also used for calibration of accelerometers.

An EAI 380 Analog/Hybird Computing System is also available for use. This is a fully expanded analog computer with a small digital section. The analog section contains amplifiers, intergraters, inverters, multipliers and function generators. The digital section contains and gates, or gates, shift registers and counters. The system can be used to perform various operations such as signal summing, integrations and linear and non-linear model construction.

A Hewlett-Packard 9830 desk top computing system is available for small computer programming. It uses the BASIC programming language. Memory size is 7904 words. Auxiliary equipment with the system include a digitizer, plotter, paper tape reader and cassette type memory. Support programs with the system include basic statistics, regression analyses and matrix operations.

For computer requirements which are larger or different than the capability of the above in-house equipment, the Aeronautical System Divisions operates a CDC 6600 computer complex that is available for use.

PHOTO DATA

Photographic film is processed using the facilities of the Aeronautical Systems Division. After it is developed and printed, a Producers Service Corporation semi-automatic film digitation system is used to track and digitize points of interest. The output is on paper tape in X-Y coordinate pairs.

Currently, after digitization, the CDC 6600 computer is used to produce trajectory plots and to estimate angular and linear velocities.

MAINTENANCE

MECHANICAL SYSTEMS

The Impulse Accelerator components require very little maintenance. However, there are certain areas which do require periodic attention. This section will review some of these as they relate to the HYGE actuator, compressor, track, sled and control system.

Reference 1 contains a list of items which should be inspected periodically. This reference suggests that the HYGE unit be disassembled every three months. However, experience has shown that once a year is adequate. The seal base O-ring will become frayed and it should be replaced whenever the metering pin is changed. Swelling of bearings had not been a problem. The condition of the bearings may be inferred by observing whether the ram moves smoothly during retract and/or set up. A small amount of Pydraul fluid will normally be carried on the ram as it extends. Should the amount be excessive, the felt wiper in the front cover should be replaced. It is very important to observe strict cleanliness whenever the actuator base has been opened. Small dirt particles can, because of the high gas velocities, seriously abrade the interior surfaces.

The Norwalk compressor also requires very little maintenance. Reference 5 contains detailed maintenance instructions for it. In day to day operation, it is sufficient to inspect and verify items such as adequate cooling water flow, proper oiler operation and proper interstage pressures. In addition, the V-drive belts should be inspected.

Cleanliness is the most important item in track maintenance. As the track runs dry and is made of untreated steel, it will rust quickly. Protective paint has been applied to the surface except for the actual sled sliding areas. These unpainted portions should be wiped down daily. If the system is to be unused for any appreciable time, a protective coating of rust preventative may be applied. It must, of course, be completely removed before using the system again. Care should also be exercised when working around the track to avoid stepping on the track surface or dropping tools on it.

The Delrin sliders and guides on the sled will wear quite rapidly, especially if firings are performed without brake pressure. Clearances should be checked against specifications monthly and cleaning and shimming performed if required.

Control system maintenance procedures are given in Reference 3. Most important of these is the maintenance required to insure that the redundant readings of system pressures are within the limits suggested in the control system section of this report.

As matter of general policy, whenever any air or N_2 line is opened, it should be blown out with air or N_2 before reconnection.

ELECTRONIC SYSTEMS

Maintenance of electronic equipment and measuring instruments falls into two

categories. Standard commercial items such as oscilloscopes or voltage generators which can be separated from the facility are periodically calibrated and serviced by the Wright-Patterson Precision Measurement Equipment Laboratory. Calibrations performed in this manner are then traceable to government standards and the accurate operation of the equipment is insured within limits of the particular item.

Many items in use on the facility are special purpose or require special maintenance techniques. These calibrations are performed on site using equipment available. The most notable requirement in this area is accelerometer calibration. An Endevco 2270 acceleration standard is maintained within the lab to perform reciprocity calibrations on the accelerometers in use. This acceleration standard and hence, all calibrations performed with it are traceable to government standards.

Basic accelerometer sensitivity is determined using a MB PM75 vibration exciter at 100 Hz. This sensitivity is used for setting up the data collection parameters. Useable frequency range and resonant frequencies are determined using a random vibration environment and the transfer function computational abilities of the Time/Data 1923 system. Periodic recalibration of accelerometers in this manner allows detection of accelerometer failures and problems.

SAMPLE PROGRAMS

Figures 16, 17, 18 and 19 depict some of the test programs which have been conducted on the Impulse Accelerator System. They show some of the ways test articles can be integrated with the system.

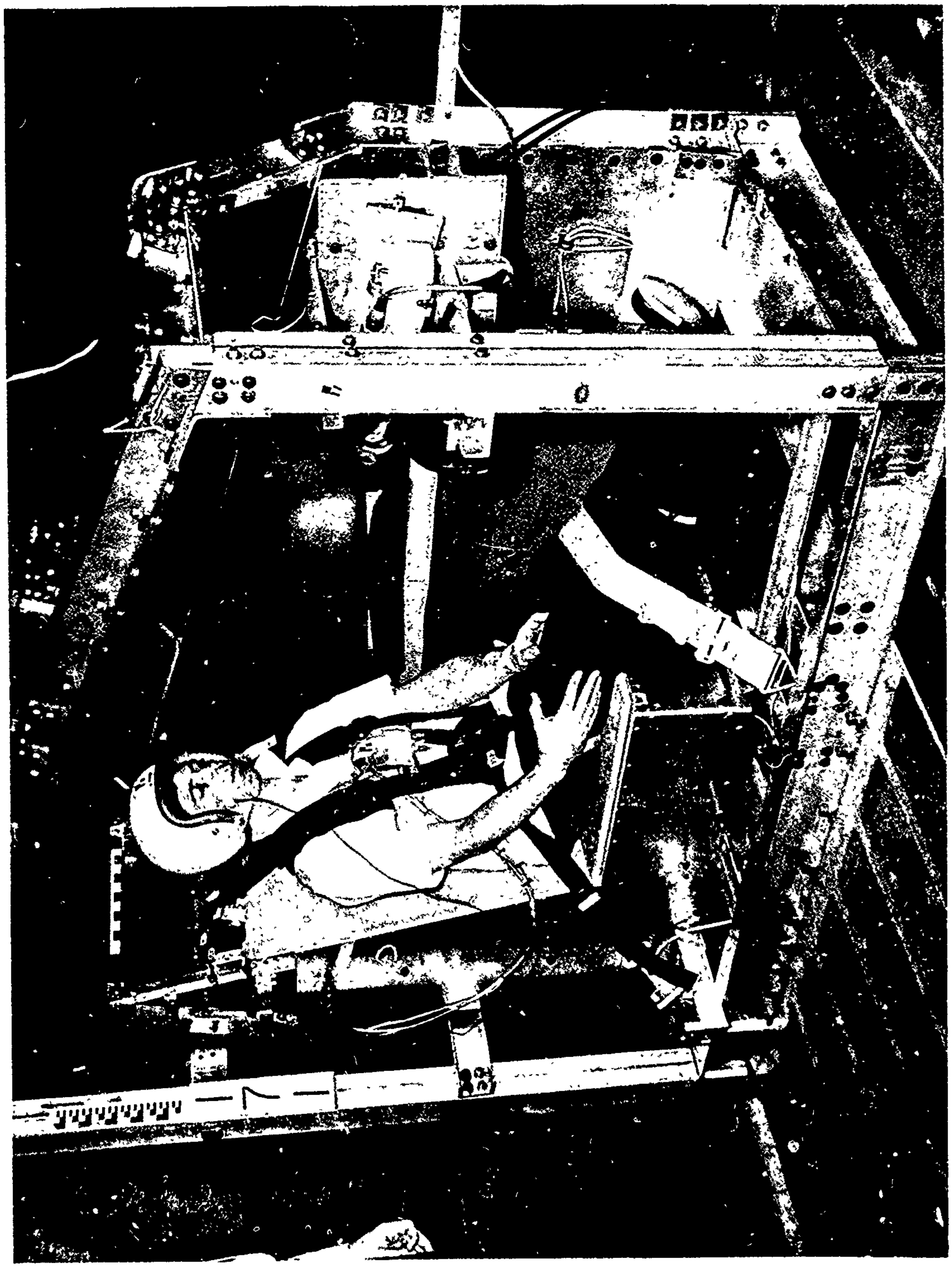


Figure 16 - LATERAL BODY SUPPORT SYSTEM TESTS

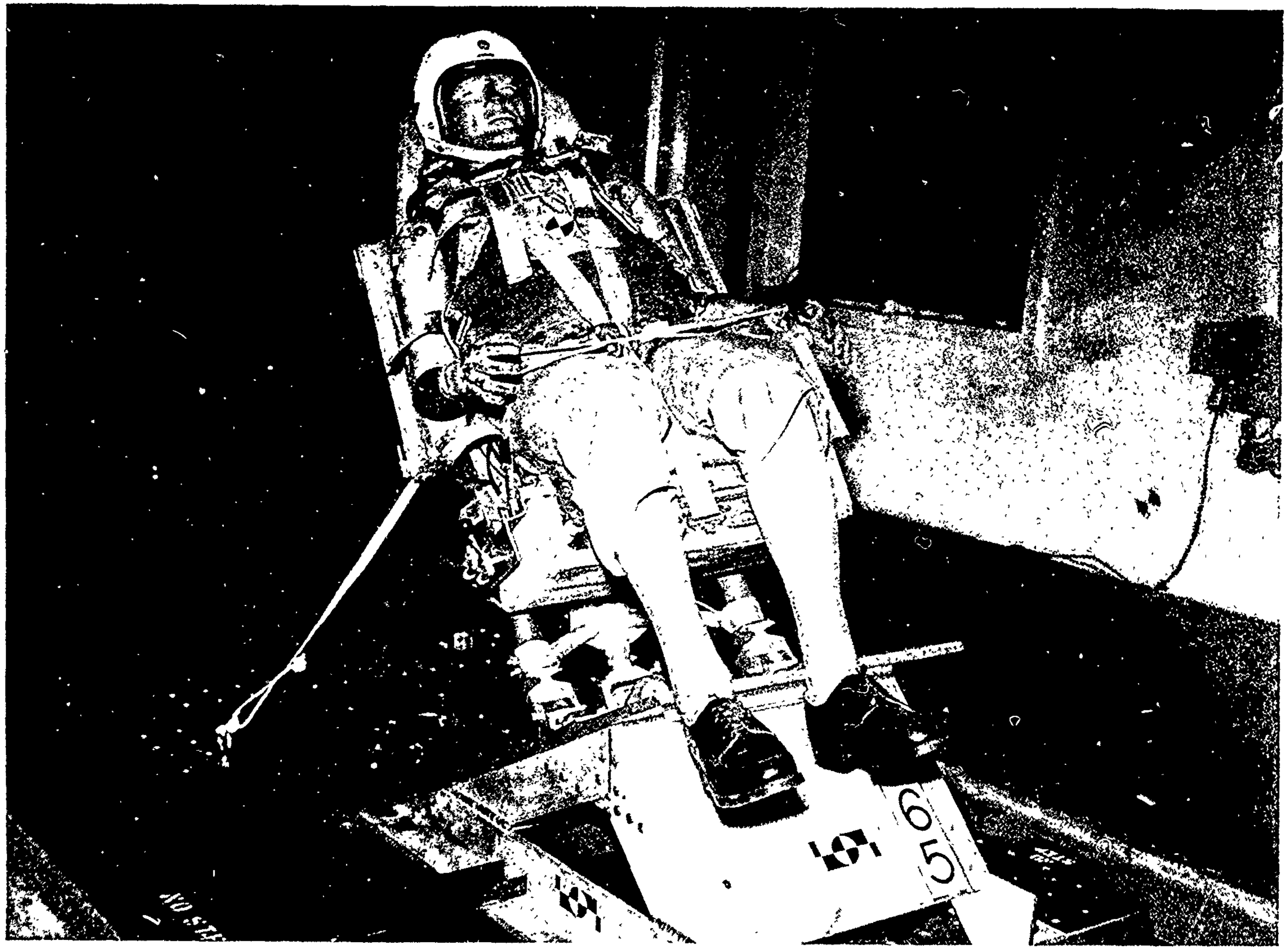


Figure 17 - ENERGY ABSORBING ARMORED HELICOPTER SEAT TESTS

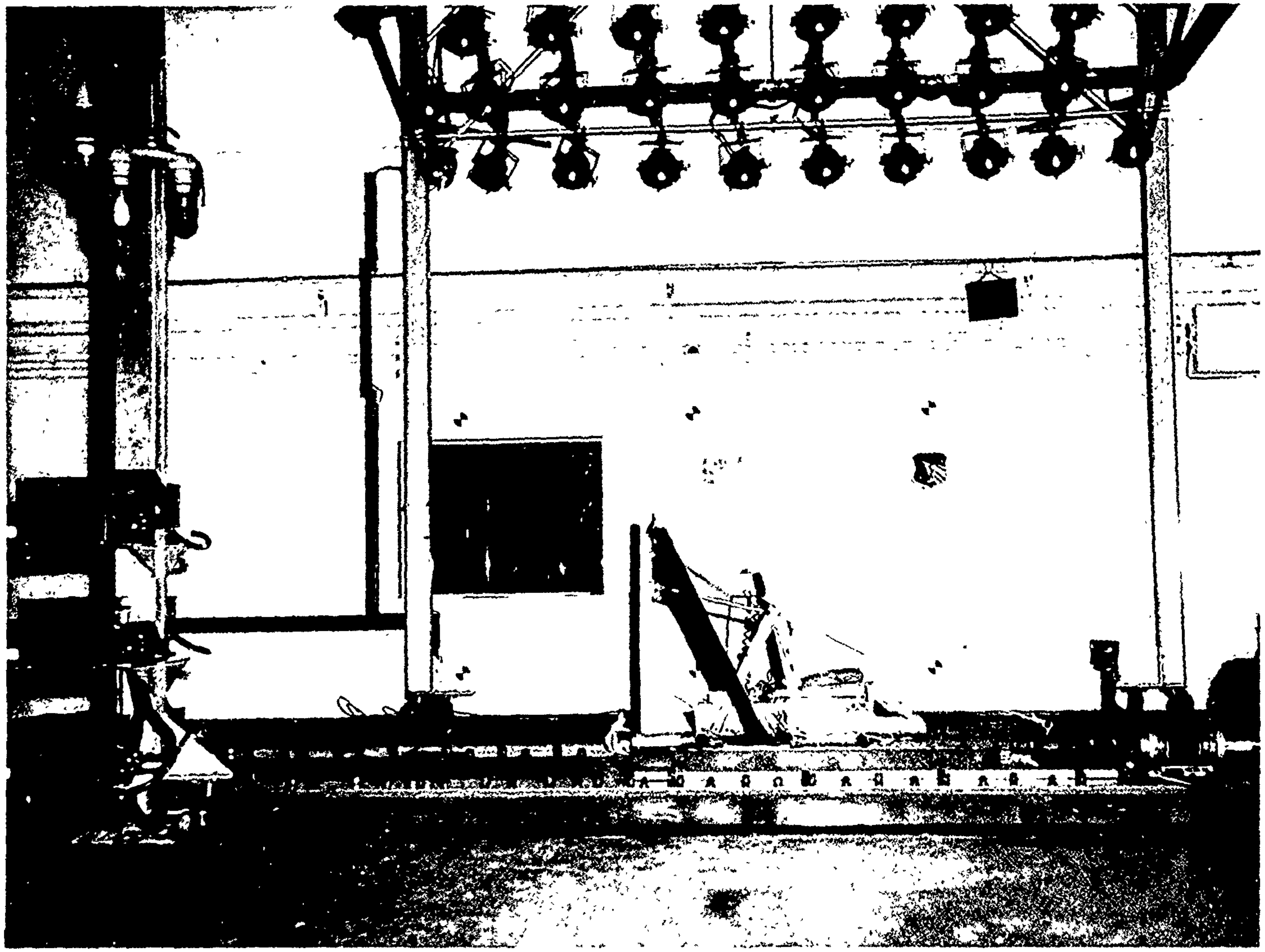


Figure 18 - THREE-POINT HARNESS INJURY EVALUATION

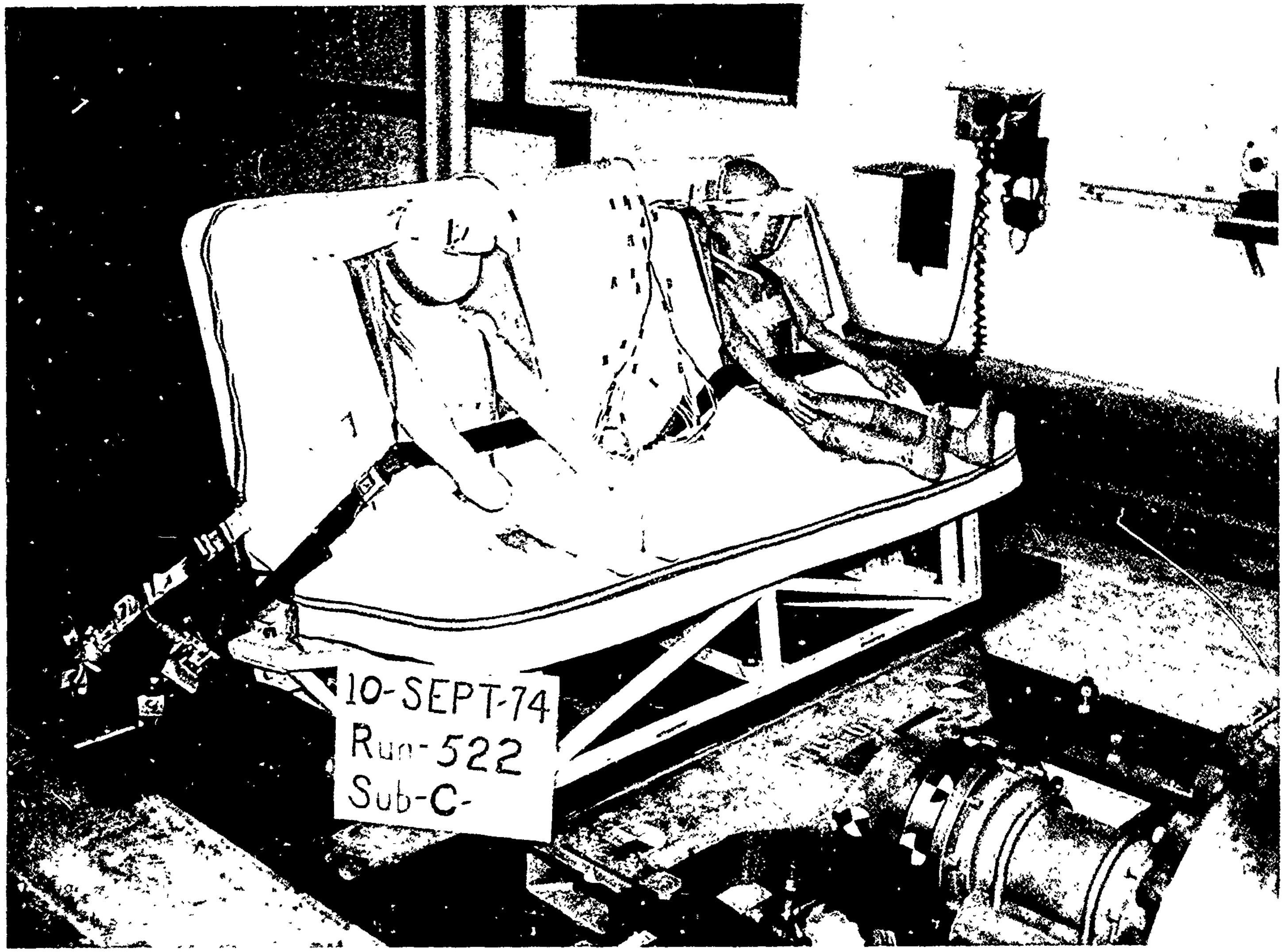


Figure 19 - CHILD RESTRAINT AND DUMMY EVALUATIONS

APPENDIX I

Governing Equations for the HYGE Actuator

GOVERNING EQUATIONS FOR HYGE SYSTEM

The basic equations which govern the motion of the HYGE actuator are given in this appendix. Some simplifying assumptions have been made in their derivations. Where parameters are not identified with the equation, they may be found on the figure at the end of this appendix.

1. Adiabatic, first law for open systems in control volume I; perfect gas.

$$\left(\frac{C_V}{R}-\frac{1}{J}\right)P_1\frac{dV_1}{dt}+\frac{C_V}{R}\left(V_1\frac{dP_1}{dt}\right)+C_p\,T_1\,\frac{dm}{dt}=0$$

2. Adiabatic, first law for open systems in control volume II; perfect gas.

$$\left(\frac{C_V}{R}+\frac{1}{J}\right)P_2\frac{dV_2}{dt}+\frac{C_V}{R}\left(V_2\frac{dP_2}{dt}\right)+C_pT_2\frac{dm}{dt}=0$$

3. Continuity equation; volumes I and II.

$$\frac{P_2V_2}{T_2}=\frac{P_{10}V_{10}}{T_{10}}-\frac{P_1V_1}{T_1}$$

4. Mass flow equation for orifice; simplified.

$$\frac{dm}{dt}=C_dA_f\left[\frac{gK}{R\left(\frac{K+1}{2}\right)^{K+1/K-1}}\right]^{1/2}\frac{P_1}{(T_1)^{1/2}}$$

5. Adiabatic, insentropic compression in control volume III.

$$P_3=P_{30}\left(\frac{V_{30}}{V_3}\right)^{Km_z}$$

6. From definition of bulk modulus in control volume IV.

$$\frac{dP_4}{dt}=-\frac{\beta}{V_{40}}\frac{dV_4}{dt}$$

7. Ram vibration equation; thrust piston end.

$$\left(m_1+\frac{m_s}{3}\right)\ddot{X}+\frac{m_s}{6}\ddot{X}_3=P_1A_{1P}+P_2A_2-P_3A_3-\frac{\dot{X}}{|\dot{X}|}f_4-\frac{\dot{X}_1-\dot{X}}{|\dot{X}_1-\dot{X}|}f_2-K|X-X_3|$$

where: $m_1=\frac{w_1}{G}$; $m_s=\frac{w_s}{G}$; G = acceleration/gravity

8. Ram vibration equation; sled end.

$$\left(m_2+\frac{m_s}{3}\right)\ddot{X}_3+\frac{m_s}{6}\ddot{X}=K(X-X_3)$$

where: $m_2=\frac{w_2}{G}$

9. Motion of set pressure piston.

$$m_3\ddot{X}_1 = A_3\left(P_3 - P_4\right) - \frac{\dot{X}_1}{|\dot{X}|} f_1 - \frac{\dot{X}-\dot{X}_1}{|\dot{X}-\dot{X}_1|} f_2$$

10. Volume of control volume I.

$$V_1 = V_{10} + \left(Vf(x)\right) \qquad X_5\left(1 - \frac{t_o}{2}\right)$$

$$V_1 = V_{10} + Vmp \qquad X_5\left(1 - \frac{t_o}{2}\right)$$

where: $Vf(X)$ = volume of metering pin in control volume I as a function of x.

Vmp = volume of metering pin

V_{10} = initial load volume minus volume of metering pin.

11. Volume of control volume II.

$$V_2 = V_{20} + A_2 x - \left(Vf(x)\right) \qquad X_5\left(1 - \frac{t_o}{2}\right)$$

$$V_2 = V_{20} + A_2 x - Vmp \qquad X_5\left(1 - \frac{t_o}{2}\right)$$

12. Volume of control volume III.

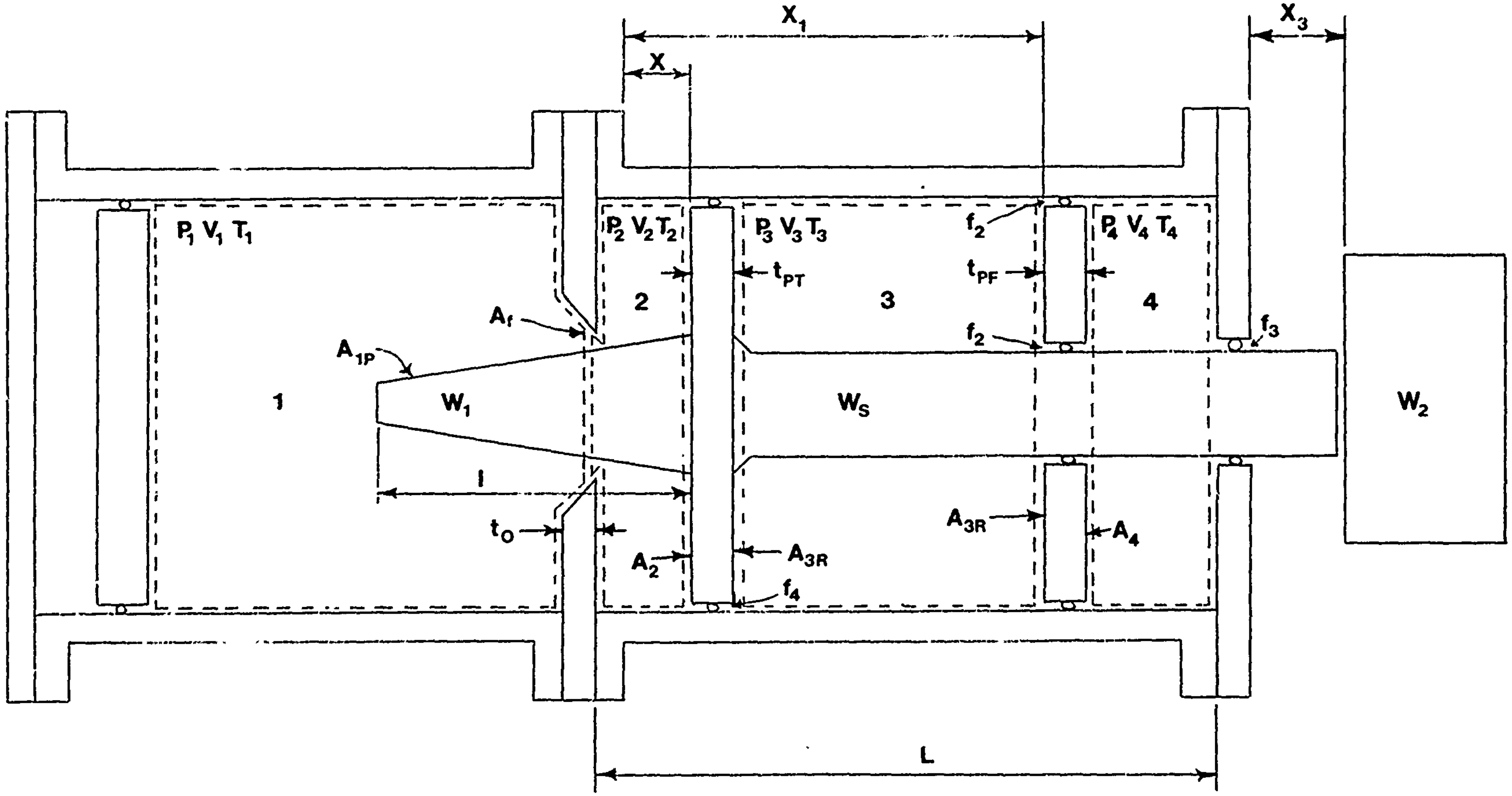
$$V_3 = V_{30} - A_3\left(X_1 - X - t_{pt}\right)$$

13. Volume of control volume IV.

$$V_4 = V_{40} - A_4 - \left(L - X_1 - t_{pf}\right)$$

14. Total internal gas volume.

$$V_1 + V_2 + V_3 + V_4 = \text{Constant}$$



Cu = Constant volume specific heat (air)
Cp = Constant pressure specific heat (air)
Cd = Orifice discharge coefficient
K_n 2 = Specific heat ratio (nitrogen)
K = specific heat ratio (air)

ANALYSIS PARAMETERS FOR HYGE ACTUATOR

APPENDIX II

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Operational Checklists and Logs

HYGE INSPECTION & OPERATION

I. Pre-fire Inspection

1. Turn power ON at power boxes marked COMPRESSOR and LIGHT RACK.
2. Check compressor oil levels - add oil if required.
3. Close HYGE air supply valve located on the compressor.
4. Open to atmosphere the atmosphere air valve.
5. Start compressor - run 5-10 minutes and check:
   a. water flow through compressor.
   b. for proper oil dripping.
6. Check nitrogen supply and reserve supply (minimum for operation is 600 psi).
7. Set pydraul systems to volume specified for program.
8. Clean and inspect track.
9. Check whip cable and place in firing position.
10. Check that sled is in contact with ram and interlock system.
11. Record run parameters, run number, date, etc., on HYGE log.

II. HYGE Power Up and Operation

1. Control station valve condition:
   a. close control and vent knobs for SET PRESSURE, LOAD PRESSURE, BRAKE PRESSURE and TRIGGER PRESSURE.
   b. open control valves for nitrogen and air supply.
2. HYGE console circuit breaker to "ON".
3. Unlock with key to power HYGE control console.
4. Compressor and compressor room checks:
   a. turn nitrogen pressure valve located in compressor room to "ON" and set regulator to 600 psi.
   b. close atmospheric air valve, open HYGE supply valve at compressor.
5. Check operation of load vent and lock yoke buttons. Leave load vent "CLOSED" and lock yokes "ENGAGED".
6. Turn mode selector key to "AUTO".
7. Turn automatic control console circuit breaker to "ON" and push power switch "IN" on intercom unit <u>and</u> control unit for power.
8. Connect nitrogen hose to brake valves and open hand valves.
9. Fill brakes to 420 psi or other specified amount and push brake reservoir switch to "ISOLATE".
10. Bleed brake pressure down to brake pressure specified for test.
11. Close brake hand valves - bleed brake lines - remove hose and place on safety switch.
12. Set thumbwheel switches for set pressure as required.
13. Set thumbwheel switches for load pressure as required.
14. Fill set cylinder to a value which <u>exceeds</u> the set pressure minimum set in thumbwheel setting.
15. After the safety light is green the load pressure key can be turned on (CW).

****** <u>WARNING</u>: After key is turned the red beacon will be on and sled area may not be approached until after firing.

16. Start compressor.

17. Fill trigger chamber to specified value which must exceed 100 psig - trigger pressure light will go to yellow.
18. Fill load cylinder to a value which is less than the value set into load pressure thumbwheel switches.
19. Stop compressor.
20. The reset button is depressed and the clock goes to the preset minus time.
21. After "SYSTEMS", "MEDICAL" and "SUBJECT" are in the green the system is armed by depressing the "ARM" button.
22. Pressing the "START" button starts the countdown c'ock.
23. After the countdown commences and prior to T equals zero the fire enable switch must be held "UP".

III HYGE Post-fire

1. After launch the load pressure key switch is turned CCW to OFF position (opens load vent).
2. Open manual load and trigger vents.
3. Check sled travel and record in HYGE test log.
4. Open brake hand valves and bleed pressure.
5. Check whip cables and test package - report damage.
6. Return sled to firing position.

IV. HYGE Shutdown

NOTE: Shutdown procedure should not be attempted until ram is fully retracted and lock yokes are engaged or all pressure is out of rear cylinder.

1. Close brake vent valve.
2. Open set pressure vent valve.
3. Check sled area is clear and dump emergency brake pressure by depressing brake switch.
4. Turn OFF compressor and light rack power boxes.
5. Bleed compressor to atmosphere - turn off nitrogen.
6. After set pressure is bled open set pressure control valve to bleed nitrogen line. CLOSE set pressure valve after nitrogen line is bled.
7. Remove pressure on lock yokes after ALL set pressure is dumped by manual cycling lock yoke button.
8. Close all control valves, open all vent valves.
9. Trip circuit breaker OFF on automatic control console.
10. Turn key locked power OFF and trip circuit breaker.

SAFETY STATION CHECK & OPERATION

I. Pre-Fire Inspection

1. Check whip cable and place in firing position.
2. Check sled for proper test or subject setup and loose parts.
3. Check sled control box for proper setup and
   a. dummy plug inserted into subject socket if human subject is not used.
   b. key turned CW for sled ready condition.

II Safety Station Power Up

1. Push power switch "IN" on intercom unit and safety control unit.

III. Safety Station Operation

1. Check that sled "CONTACT" light is in green.
2. After brakes are filled, check:
   a. that "sled" ready is in green.
   b. that "hose/cable" is in green.
3. Test beacon and klaxon systems, then switch to "OFF" position.

The next checks are made immediately prior to filling the load cylinder or as requested by the machine operator.

4. The area is secured - doors closed (indicated by green light) and locked.
5. The light fence is activated (indicated by green light).
6. Light fence operation to "AUTO".
7. Observer switch should be in "OVERRIDE".
8. "LOG" and PA should be in normal if operator requires recording intercom and PA conversation.
9. Intercom to "CHECKED" position after intercom check.
10. Activate klaxon by switching to "TESTED" position.
11. Activate beacon by switching to "TESTED" position.
12. Depress "PRESSURIZE ENABLE" button to allow operator to close load vent and commence filling.
13. After the countdown commences and prior to T equal zero the fire enable switch must be up.

IV. Safety Station - Post Fire

1. Turn light fence off.
2. Unlock doors.

V. Safety Station - Power Down

1. Klaxon "OFF".
2. Beacon "OFF".
3. Log and PA to override.

MEDICAL MONITOR STATION OPERATIONAL CHECKLIST

POWER ON

1. Intercom power "ON".
2. Medical station power "ON".

STATION OPERATION

1. If medical monitor requires right to declare subject ready or the right to "abort", the following procedure should be followed:

   a. The dummy plug should be positioned in the storage location on the unit.
   b. The monitor's switch should be plugged into the switch location on the unit.
   c. The medical monitor declares a "ready" condition by holding the switch depressed. By releasing the switch after countdown commences the clock will stop at T-10 seconds or abort and disarm the system if released under T-10 seconds.

2. If no medical monitoring is required the dummy plug is positioned in the "switch" position and the monitor's switch is positioned in the dummy position

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HYGE CAMERA STATION OPERATIONAL CHECKLIST

COLORTRAN CHECK

1. Input voltage selector to 200 V.
2. Main power switch and circuit breaker "ON".
3. Output voltage control switches to pos. 1.

POWER ON (Circuit breaker on HYGE operators control console MUST BE ON and power applied)

1. Dearing L.E.D. driver power "ON".
2. Camera and lighting station "ON".
3. Intercom station "ON".
4. Power applied to fixed camera distribution box.
5. DC power "ON" and set for on-board cameras (DC voltage controls camera speed and is determined by Camera Tech).
6. Pre-count status switch to "Not Ready".

STATION CHECK

1. All manual/auto switches to manual.
   Note: Purge power relay box with N_2 prior to turning lights on.
2. Initiate manual "ON" for light comparator (lights should sequence on). Initiate manual "OFF" (if lights fail to come on check master circuit breaker in compressor room).
3. With cameras connected the L.E.D.'s should be checked for operation and brightness. Initiate manual "ON" for auxiliary comparator.

   All L.E.D.'s should come on bright. Rotate switch on L.E.D. driver and check for specified current thru L.E.D.'s on cameras connected.
4. If fixed cameras are cabled in they can be checked for operation by initiating a manual "ON" then "OFF".
5. If on-board cameras are cabled in they can be checked for operation by initiating a manual "ON" then "OFF".

OPERATIONAL READINESS

1. Set comparator switches for lights, fixed cameras, on board cameras and auxiliary as required (Aux is timing and is set for "on" T+00, "off" T+02).
2. Place normal/override switches in "normal" for stations with current check, "override" for stations not using current check.
3. Place manual/auto switches in "auto" position.
4. Pre-count switch to "ready".

POWER DOWN

1. Auto/manual switches to manual.
2. Pre-count status to NOT READY.
3. Turn DC power off.
4. Disconnect AC power to fixed camera distribution box.

HYGE TEST LOG

RUN NO.______________ DATE______________

PROJECT______________ -HUMAN______________

______________ -DUMMY______________

______________ -ANIMAL______________

-OTHER______________

NOMINAL CONDITIONS __________G ______________FT/SEC

HYGE FIRE DATA

______HALF SINE PIN SET VOLUME LENGTH______

______SQUARE WAVE PIN LOAD VOLUME LENGTH______

NORMAL BRAKE PRESSURE______ AUXILIARY PRESSURE______

SET PRESSURE__________ LOAD PRESSURE________

TRIGGER PRESSURE______

MEASURED DATA

SLED TRAVEL________

TEST WEIGHT________ TOTAL WEIGHT________

PEAK G__________ RISE TIME__________ TOTAL TIME________

SEPARATION VELOCITY________

DECELERATION LEVEL________

REMARKS

____

____

____

____

HYGE

INSTRUMENTATION LOG

FACILITY________________________ TEST NO.____________

PROGRAM________________________ DATE____________

PEAK G____________

PERFORMANCE

DATA POINT PROBLEM CORRECTIVE ACTION

EQUIPMENT AND WHIP CABLE

EOUIPMENT PROBLEM CORRECTIVE ACTION

SPECIAL NOTATIONS

VTD DATA

VEL-

DISP-

DUR-

May 74 TECHNICIAN INITIALS__________

HYGE

CAMERA STATION LOG

TEST NO.____________________ DATE_______________________

COLORTRAN LIGHT SETTING______________________________

LIGHT COMPARATOR ON_________________ OFF____________

FIXED CAMERA COMPARATOR ON_________________ OFF____________

SLED CAMERA COMPARATOR ON_________________ OFF____________

AUX COMPARATOR-TIMING ON_________________ OFF____________

NEON DRIVER INTENSITY SETTING_______________________

CAMERA OPERATIONAL STATUS (IF POSITION IS USED & RESULTS)

FIXED NO. 1 -

NO. 2 -

NO. 3 -

NO. 4 -

NO. 5 -

SLED NO. 1 -

NO. 2 -

NO. 3 -

COMMENTS:

26 Nov 73

PROCEDURE FOR CHANGING SET AND LOAD VOLUME LENGTHS *

A. TO INCREASE SET VOLUME LENGTH

1. Move sled away from ram at least 15 feet.
2. Power up HYGE console and air compressor.
3. Turn on N_2 supply.
4. Set key switch to "MANUAL" mode.
5. Run compressor and build up 500 psig in accumulator.
6. Check rope, hose and intercom switches for closure.
7. Block sled contact switch closed.
8. Put 15 psig N_2 in set chamber.
9. Close load and trigger pressure manual vent valves.
10. Close load vent solenoid valve.
11. Retract lock yokes.
12. Activate trigger switch and hold up operator's "fire enable" switch.
13. Pressurize trigger chamber until ram unseats (~15 psig).
14. Release "fire enable" switch and continue to pressurize through load chamber valve. Keep pressure below 50 psig.
15. Remove block from sled contact switch.
16. Open manual set pressure vent valve and depress set pressure vent bypass switch.
17. Hold switch until ram stops forward travel and then release.
18. Open hydraulic valve under front cylinder.
19. Open tank valve only at set chamber fluid reservoir.
20. Push hydraulic fluid into reservoir with air pressure. Keep pressure below 80 psig.
21. At desired length, close tank valve.
22. Stop compressor and close hydraulic valve under front cylinder.
23. Open and close tank valve to relieve pressure on transfer hose.
24. Open load vent solenoid valve.
25. Depress set pressure vent bypass switch.
26. Admit N_2 to set chamber to retract ram.
27. When ram has seated against orifice and lock yokes have automatically engaged, release set pressure vent bypass switch.
28. After load pressure has completed venting, vent N_2 gas from set chamber.
29. Power down HYGE console and relieve all system pressures.
30. Return sled to fire position.

B. TO DECREASE SET VOLUME LENGTH

1. Perform steps 1 through 18 of procedure A.
2. Open both tank vlave and pump valve at set chamber reservoir.
3. Open manual load pressure vent valve.
4. Pump hydraulic fluid into set cylinder.
5. At desired length, stop pump.
6. Close hydraulic valve under front cylinder.

* These procedures should only be performed by or under the supervision of experienced personnel.

7. Close pump valve and tank valve.
8. Perform steps 25 through 29 of Procedure A.

C. TO INCREASE LOAD VOLUME LENGTH

1. Perform steps 2 through 5 of Procedure A.
2. Put 80 psig in set chamber.
3. Open hydraulic valve on bottom of rear cylinder.
4. Open tank valve at load chamber reservoir.
5. Close load and trigger pressure vent valves.
6. Close load vent solenoid valve.
7. Push hydraulic fluid into reservoir with air pressure. Keep pressure below 80 psig.
8. At desired length as read on reservoir sight glass, close tank valve.
9. Stop compressor and close hydraulic valve under rear cylinder.
10. Open and close tank valve to relieve pressure on transer hose.
11. Open load vent solenoid valve.
12. Perform steps 27 and 28 of Procedure A.

D. TO DECREASE LOAD VOLUME LENGTH

1. Perform steps 1 through 3 of Procedure C.
2. Open tank valve and pump valve at load chamber reservoir.
3. Open load pressure vent valves (manual and solenoid).
4. Pump hydraulic fluid into load cylinder.
5. At desired length as read on sight glass, stop pump.
6. Close hydraulic valve under rear cylinder.
7. Close pump valve and tank valve.
8. Perform steps 27 and 28 of Procedure A.

APPENDIX III

Performance Charts

Figure 1

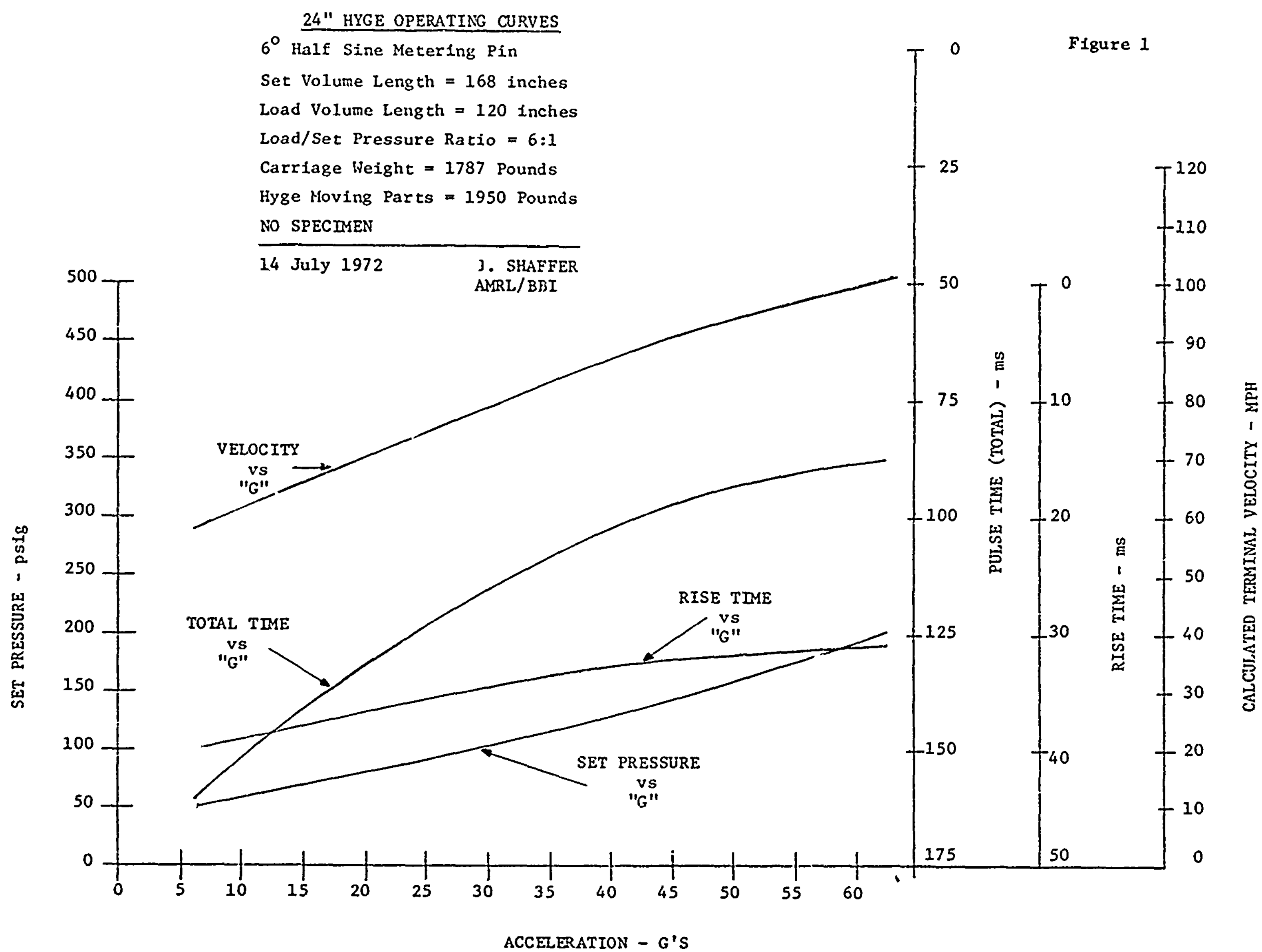
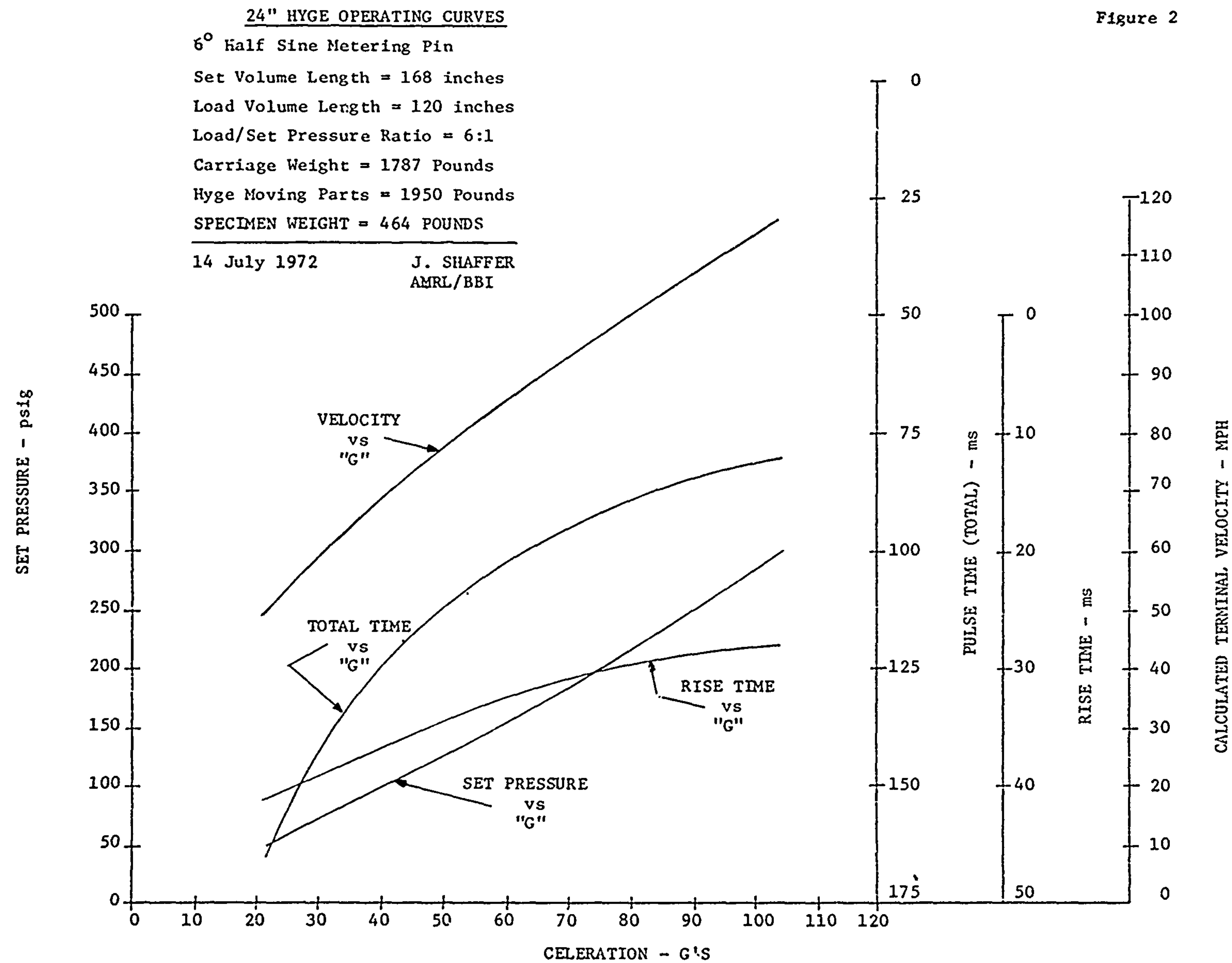

24" HYGE OPERATING CURVES
6° Half Sine Metering Pin
Set Volume Length = 168 inches
Load Volume Length = 120 inches
Load/Set Pressure Ratio = 6:1
Carriage Weight = 1787 Pounds
Hyge Moving Parts = 1950 Pounds
NO SPECIMEN
14 July 1972
J. SHAFFER
AMRL/BBI
VELOCITY vs "G"
TOTAL TIME vs "G"
RISE TIME vs "G"
SET PRESSURE vs "G"
SET PRESSURE - psig
0
50
100
150
200
250
300
350
400
450
500
ACCELERATION - G'S
0
5
10
15
20
25
30
35
40
45
50
55
60
PULSE TIME (TOTAL) - ms
0
25
50
75
100
125
150
175
RISE TIME - ms
0
10
20
30
40
50
CALCULATED TERMINAL VELOCITY - MPH
0
10
20
30
40
50
60
70
80
90
100
110
120

Figure 2



24" HYGE OPERATING CURVES
6° Half Sine Metering Pin
Set Volume Length = 168 inches
Load Volume Length = 120 inches
Load/Set Pressure Ratio = 6:1
Carriage Weight = 1787 Pounds
Hyge Moving Parts = 1950 Pounds
SPECIMEN WEIGHT = 464 POUNDS
14 July 1972
J. SHAFFER
AMRL/BBI
VELOCITY vs "G"
TOTAL TIME vs "G"
RISE TIME vs "G"
SET PRESSURE vs "G"
SET PRESSURE - psig
PULSE TIME (TOTAL) - ms
RISE TIME - ms
CALCULATED TERMINAL VELOCITY - MPH
CELERATION - G'S

Figure 3

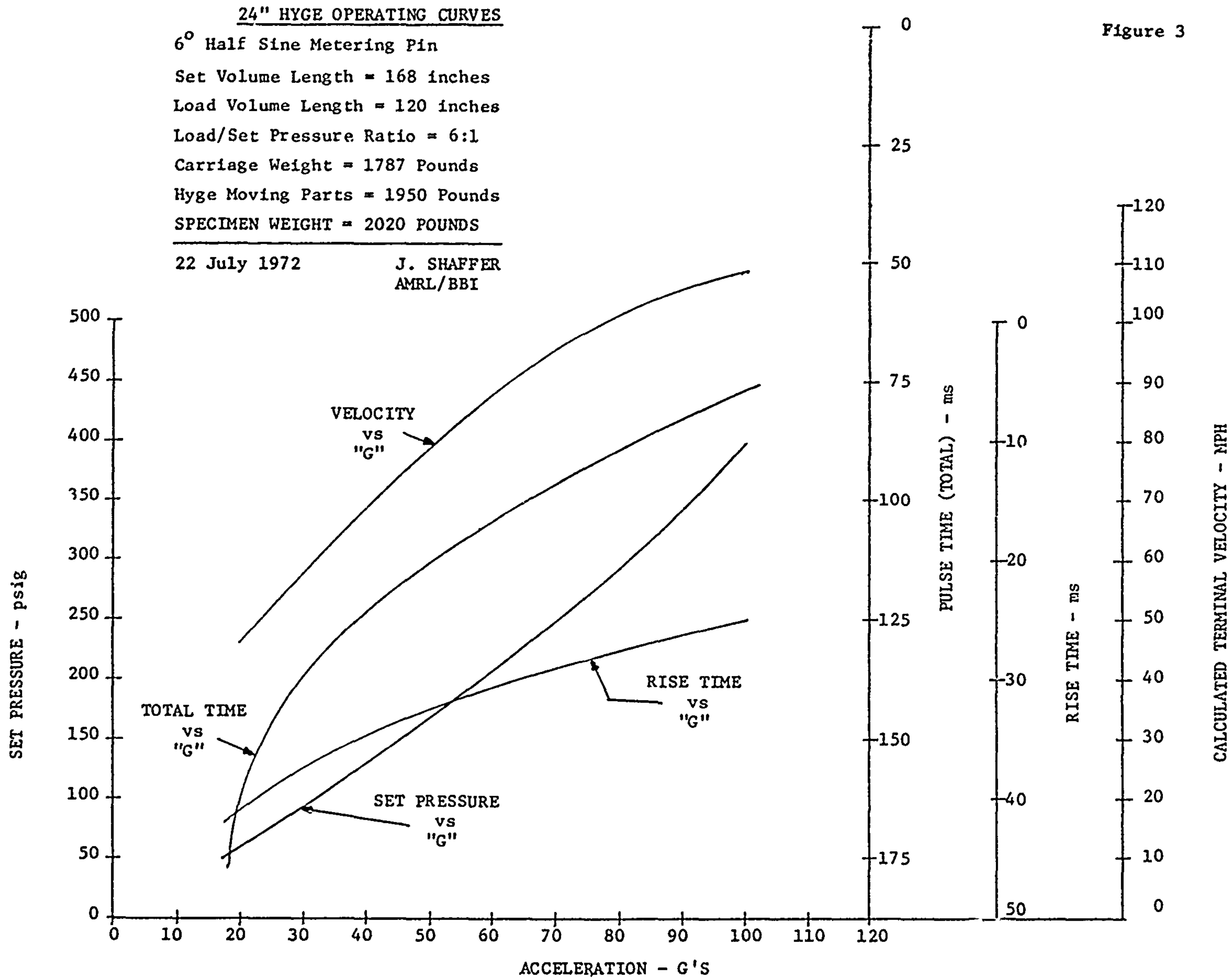

24" HYGE OPERATING CURVES
6° Half Sine Metering Pin
Set Volume Length = 168 inches
Load Volume Length = 120 inches
Load/Set Pressure Ratio = 6:1
Carriage Weight = 1787 Pounds
Hyge Moving Parts = 1950 Pounds
SPECIMEN WEIGHT = 2020 POUNDS
22 July 1972
J. SHAFFER
AMRL/BBI
VELOCITY vs "G"
TOTAL TIME vs "G"
SET PRESSURE vs "G"
RISE TIME vs "G"
SET PRESSURE - psig
0
50
100
150
200
250
300
350
400
450
500
ACCELERATION - G'S
0
10
20
30
40
50
60
70
80
90
100
110
120
PULSE TIME (TOTAL) - ms
0
25
50
75
100
125
150
175
RISE TIME - ms
0
10
20
30
40
50
CALCULATED TERMINAL VELOCITY - MPH
0
10
20
30
40
50
60
70
80
90
100
110
120

Figure 4

LATERAL RESTRAINT PROGRAM

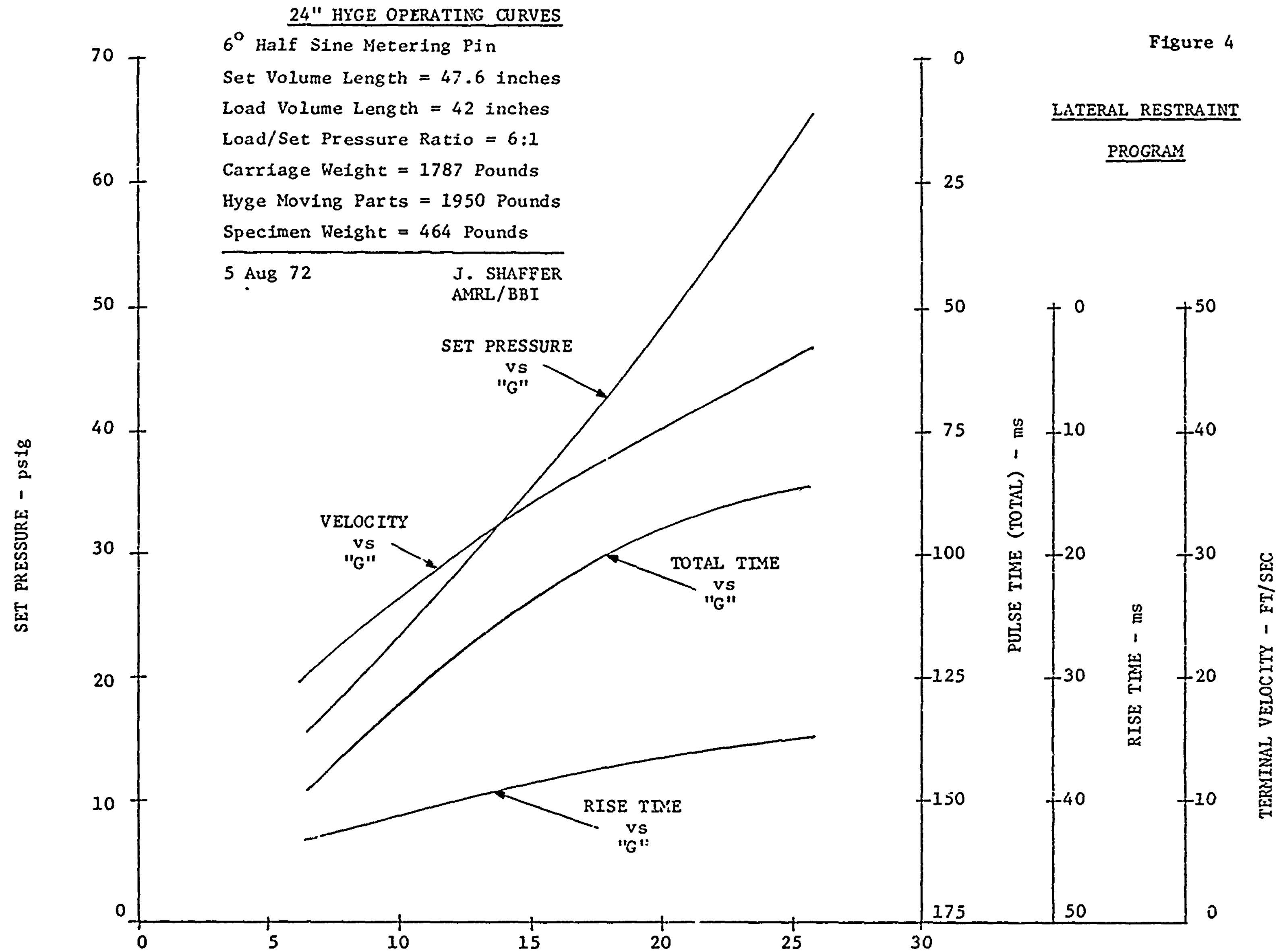


Figure 5

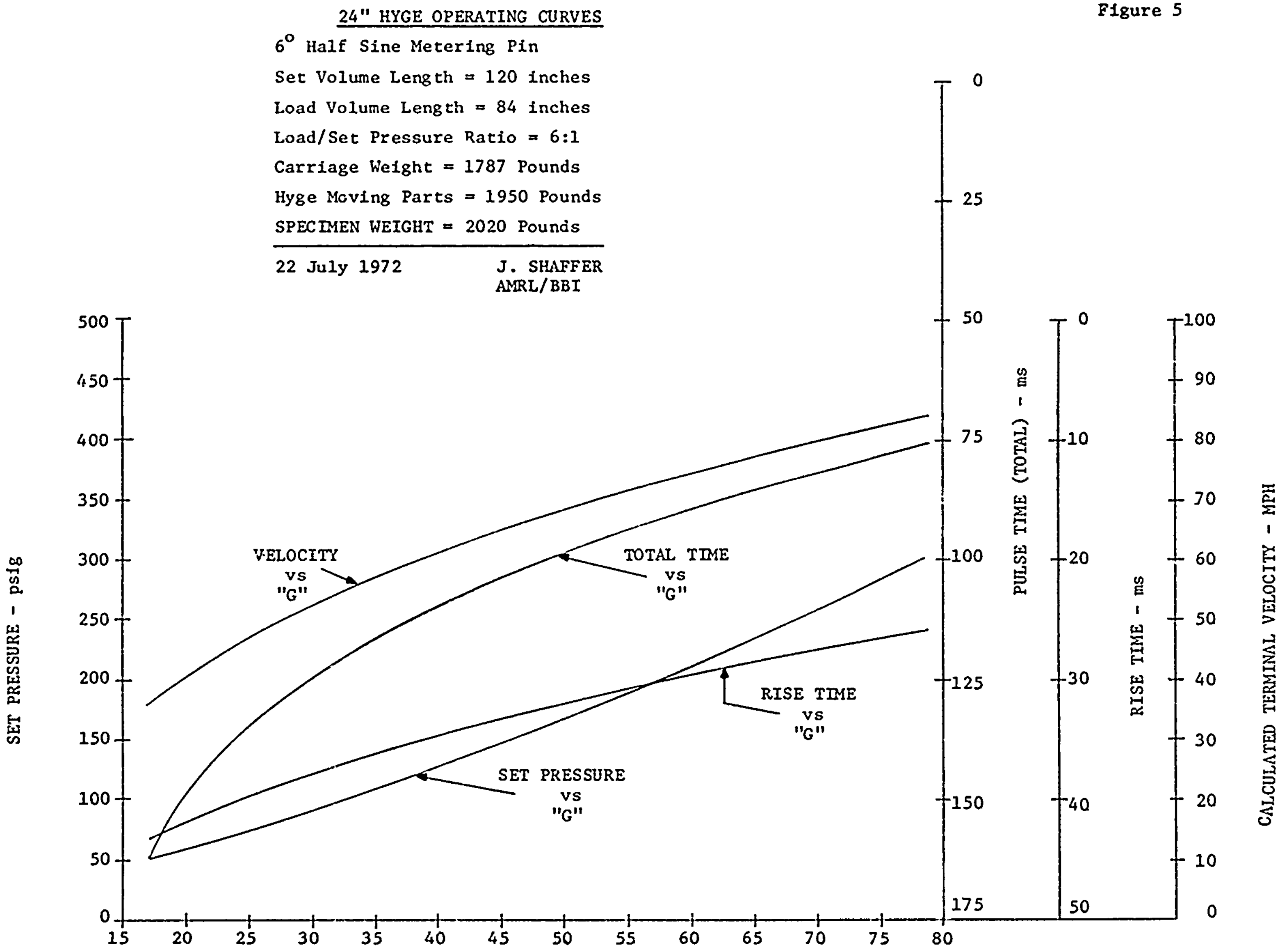

24" HYGE OPERATING CURVES
6° Half Sine Metering Pin
Set Volume Length = 120 inches
Load Volume Length = 84 inches
Load/Set Pressure Ratio = 6:1
Carriage Weight = 1787 Pounds
Hyge Moving Parts = 1950 Pounds
SPECIMEN WEIGHT = 2020 Pounds
22 July 1972
J. SHAFFER
AMRL/BBI
SET PRESSURE - psig
0
50
100
150
200
250
300
350
400
450
500
15
20
25
30
35
40
45
50
55
60
65
70
75
80
VELOCITY vs "G"
TOTAL TIME vs "G"
RISE TIME vs "G"
SET PRESSURE vs "G"
PULSE TIME (TOTAL) - ms
0
25
50
75
100
125
150
175
RISE TIME - ms
0
10
20
30
40
50
CALCULATED TERMINAL VELOCITY - MPH
0
10
20
30
40
50
60
70
80
90
100

Figure 6

24" HYGE OPERATING CURVES

6° Half Sine Metering Pin

60 MS HALF SINE PULSE

Set Pressure Volume Length - See Curve

Load Pressure Volume Length = 60 inches

Load/Set Pressure Ratio = 6:1

Carriage Weight = 1787 Pounds

Hyge Moving Parts = 1950 Pounds

Specimen Weight = 2020 Pounds

22 July 1972

J. SHAFFER
AMRL/BBI

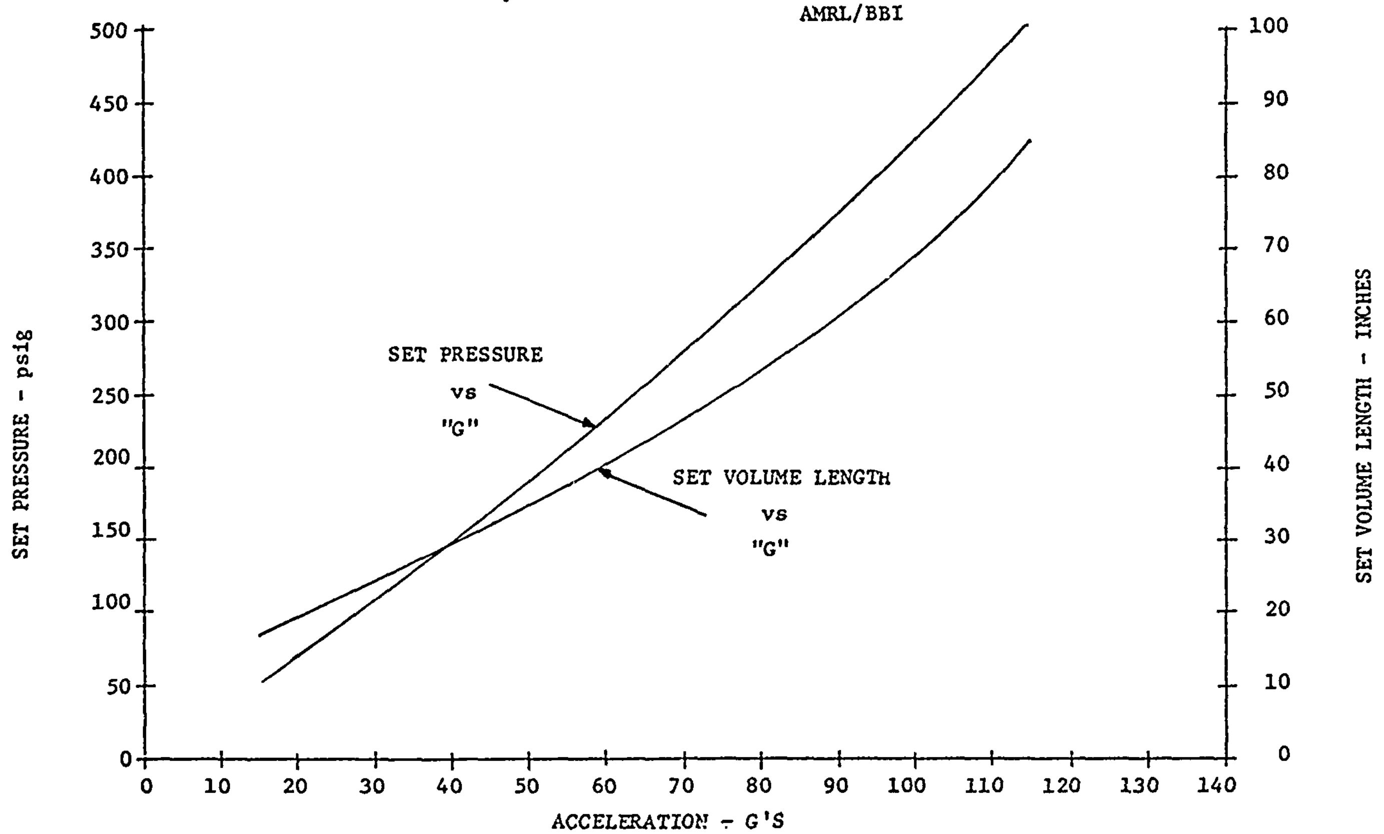


Figure 7

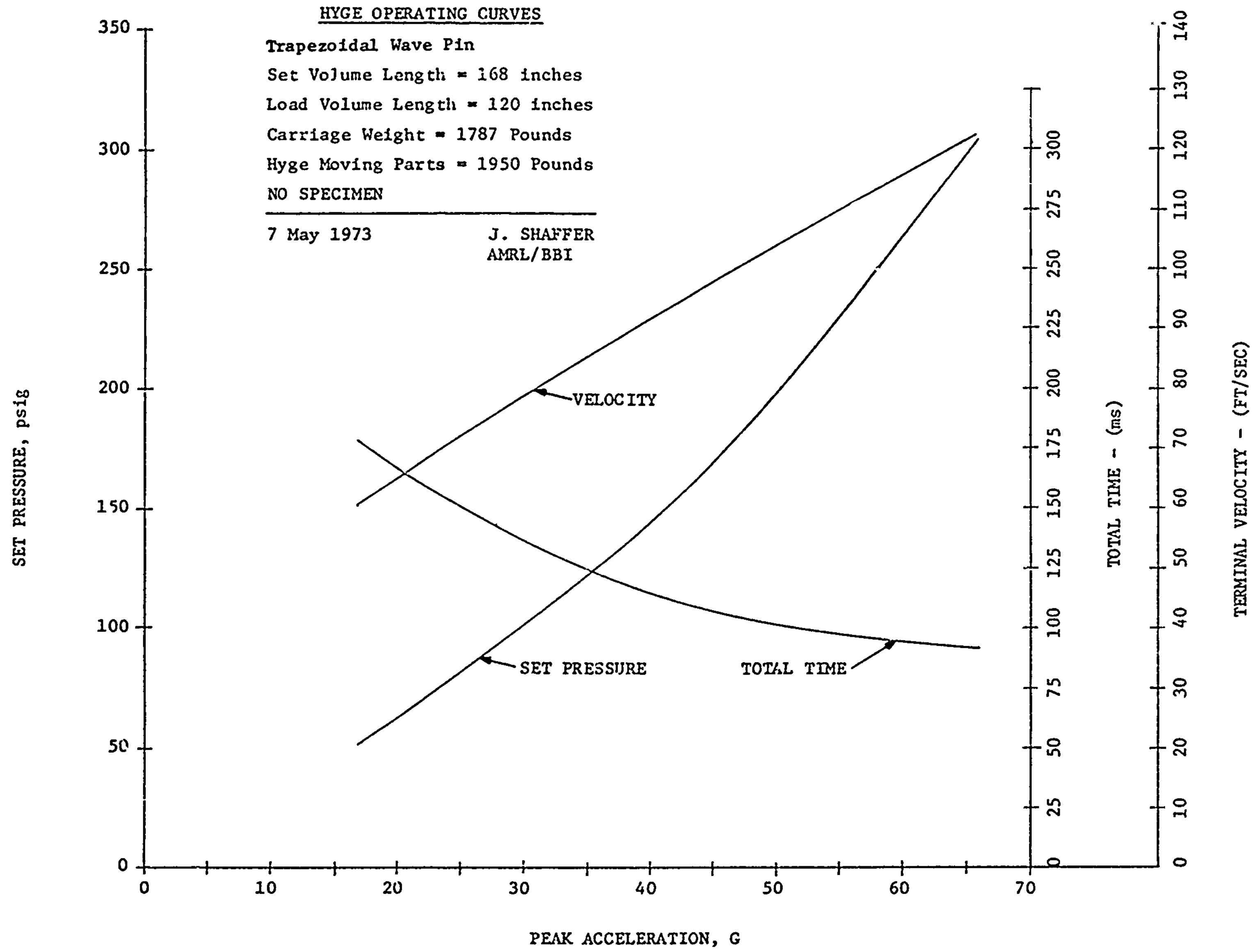
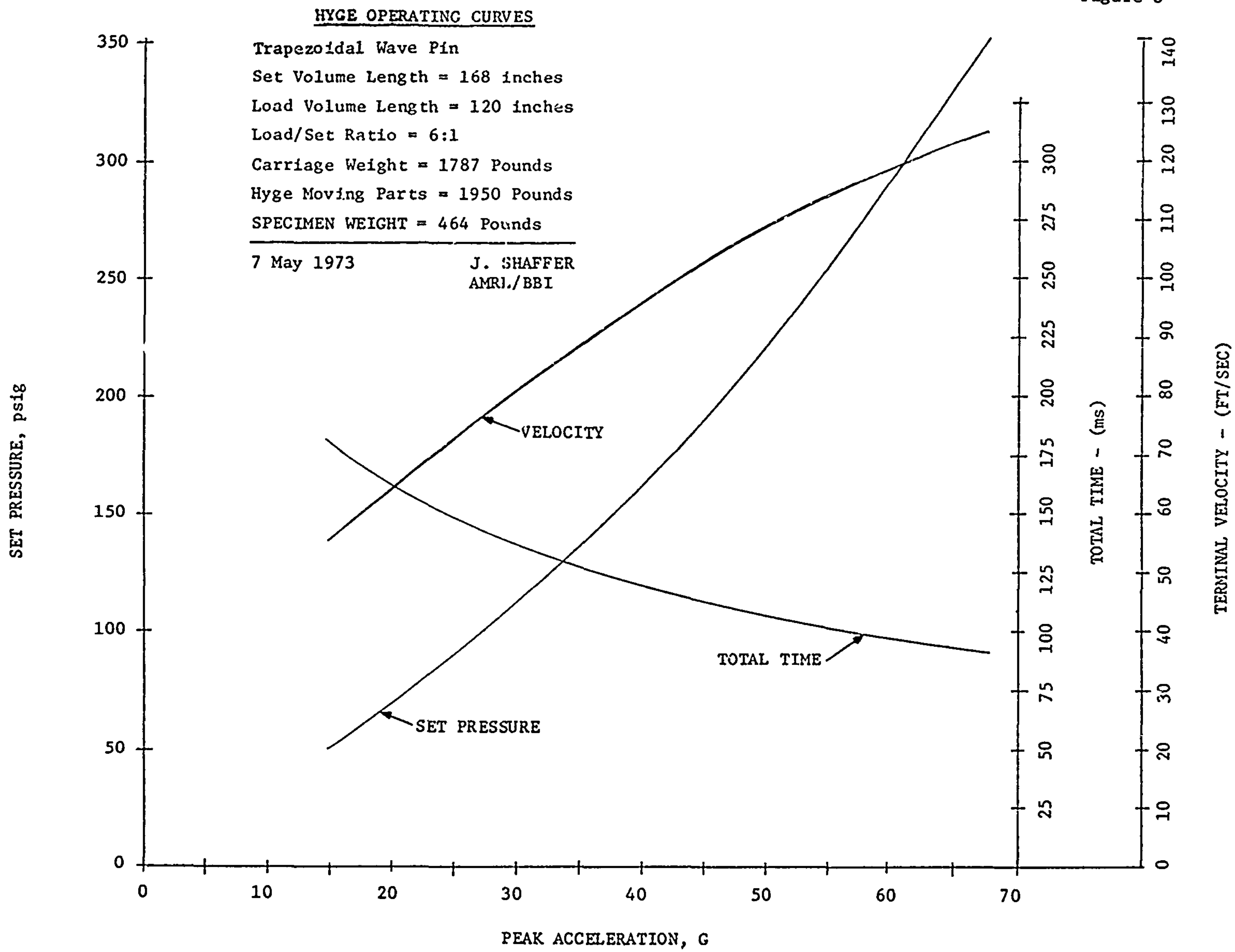
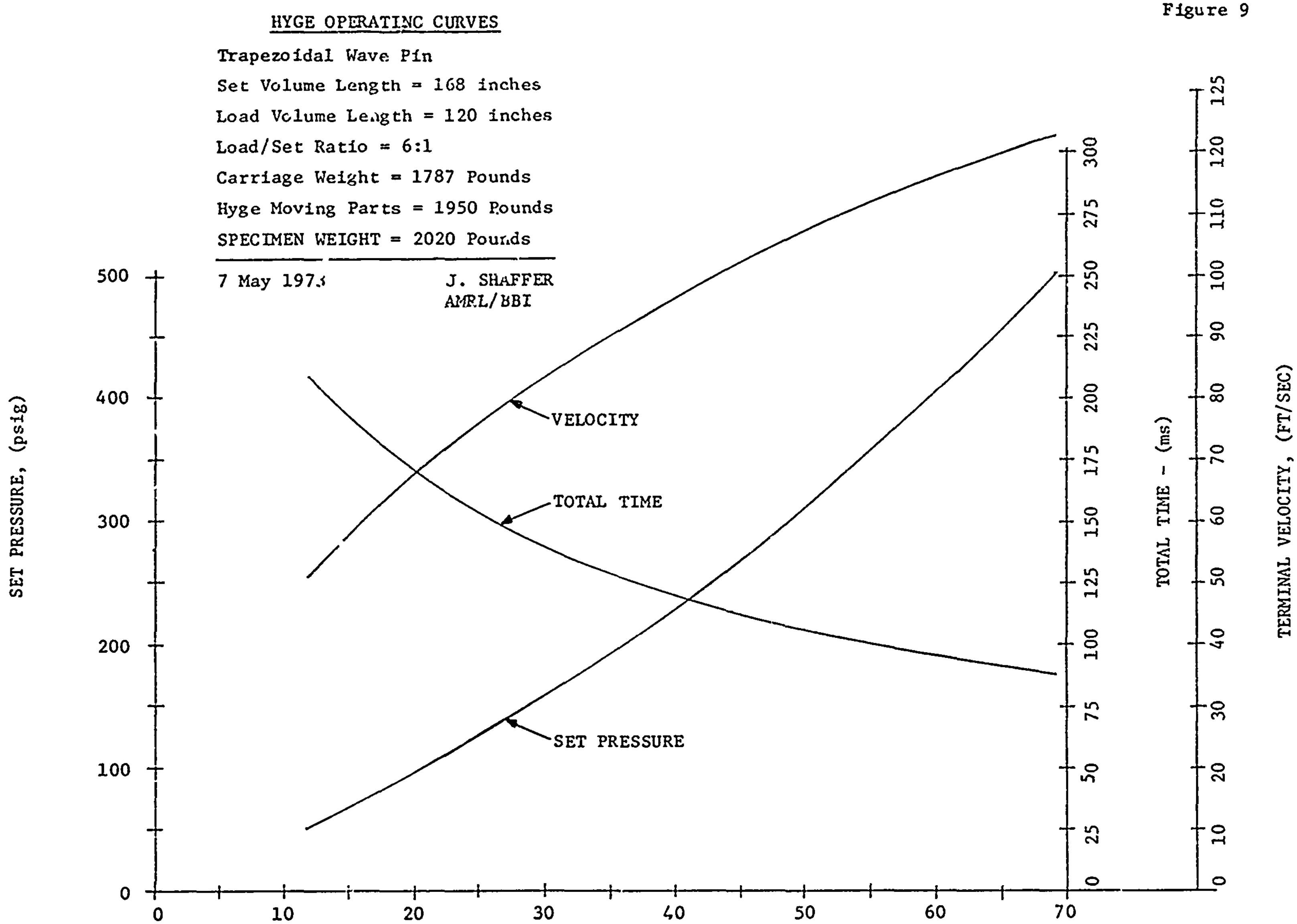

HYGE OPERATING CURVES
Trapezoidal Wave Pin
Set Volume Length = 168 inches
Load Volume Length = 120 inches
Carriage Weight = 1787 Pounds
Hyge Moving Parts = 1950 Pounds
NO SPECIMEN
7 May 1973
J. SHAFFER
AMRL/BBI
VELOCITY
SET PRESSURE
TOTAL TIME
SET PRESSURE, psig
TOTAL TIME - (ms)
TERMINAL VELOCITY - (FT/SEC)
PEAK ACCELERATION, G
0
10
20
30
40
50
60
70
0
50
100
150
200
250
300
350
0
25
50
75
100
125
150
175
200
225
250
275
300
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140

Figure 8



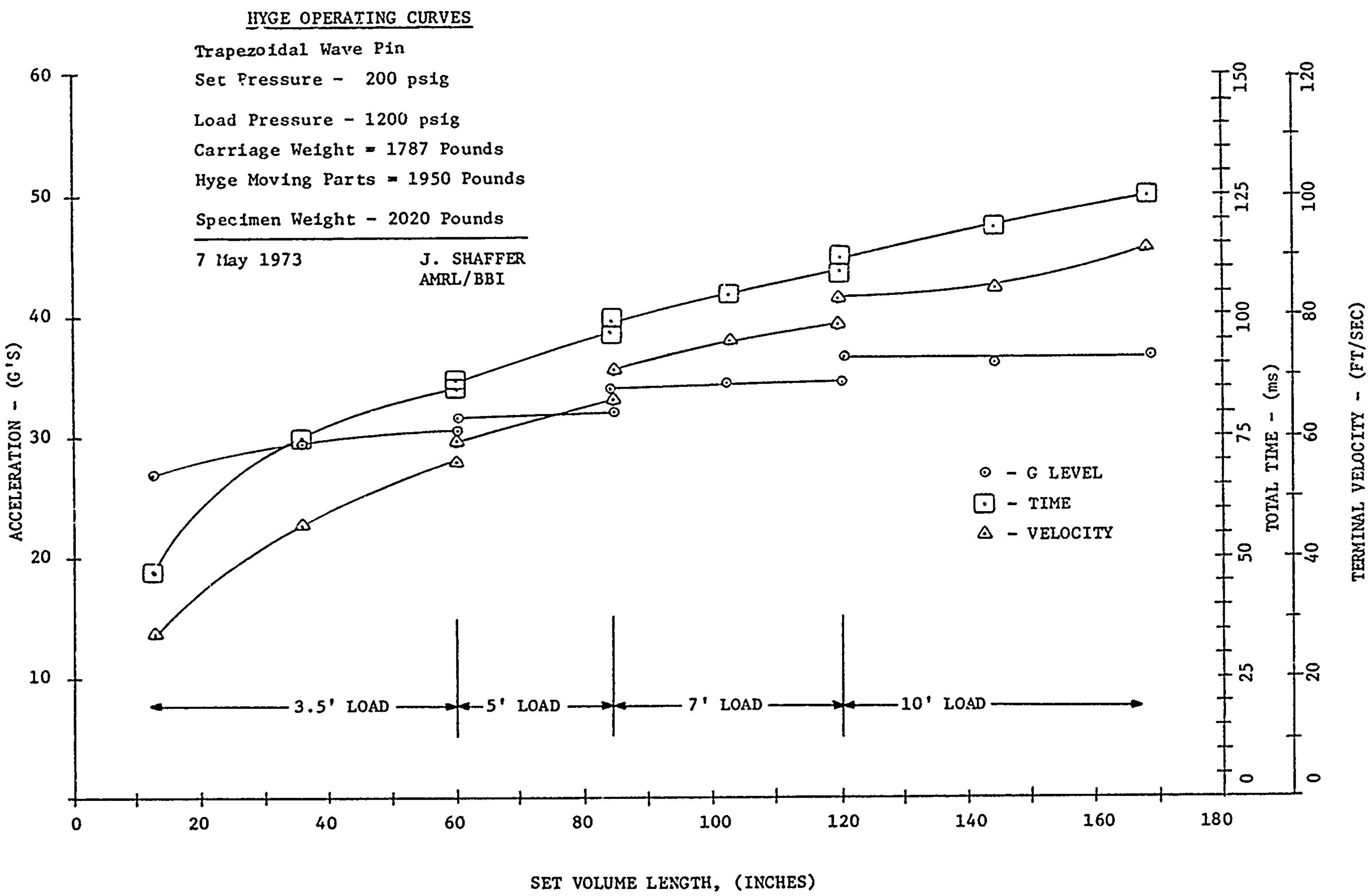
HYGE OPERATING CURVES
Trapezoidal Wave Pin
Set Volume Length = 168 inches
Load Volume Length = 120 inches
Load/Set Ratio = 6:1
Carriage Weight = 1787 Pounds
Hyge Moving Parts = 1950 Pounds
SPECIMEN WEIGHT = 464 Pounds
7 May 1973
J. SHAFFER
AMRL/BBI
VELOCITY
TOTAL TIME
SET PRESSURE
SET PRESSURE, psig
PEAK ACCELERATION, G
TOTAL TIME - (ms)
TERMINAL VELOCITY - (FT/SEC)
0
50
100
150
200
250
300
350
10
20
30
40
60
70
25
75
125
175
225
275
80
90
110
120
130
140

Figure 9



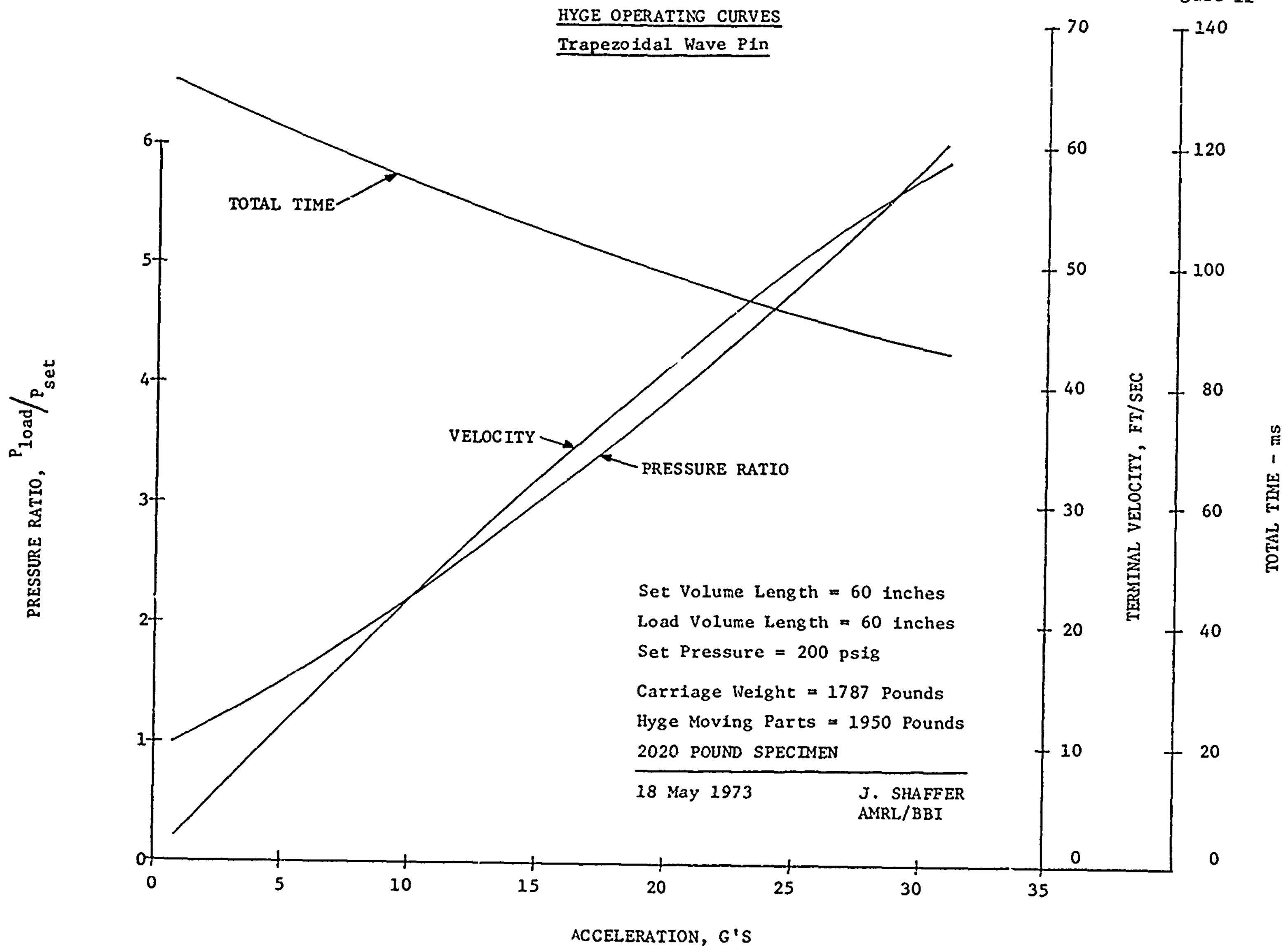
HYGE OPERATING CURVES
Trapezoidal Wave Pin
Set Volume Length = 168 inches
Load Volume Length = 120 inches
Load/Set Ratio = 6:1
Carriage Weight = 1787 Pounds
Hyge Moving Parts = 1950 Pounds
SPECIMEN WEIGHT = 2020 Pounds
7 May 1973
J. SHAFFER
AMRL/BBI
VELOCITY
TOTAL TIME
SET PRESSURE
SET PRESSURE, (psig)
TOTAL TIME - (ms)
TERMINAL VELOCITY, (FT/SEC)
0
100
200
300
400
500
10
20
30
40
50
60
70
25
75
125
150
175
225
250
275
80
90
110
120

Figure 10



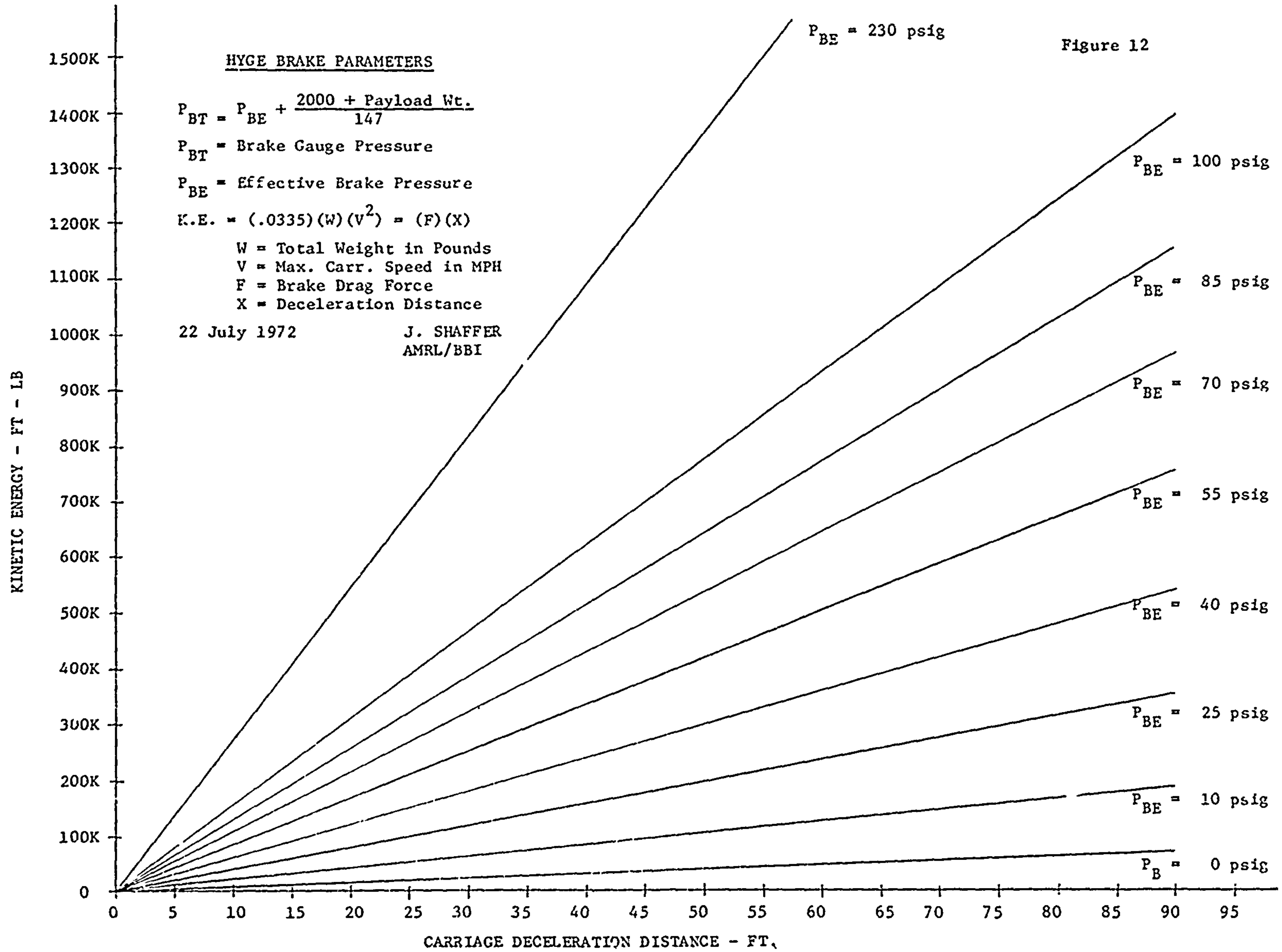
HYGE OPERATING CURVES
Trapezoidal Wave Pin
Set Pressure - 200 psig
Load Pressure - 1200 psig
Carriage Weight = 1787 Pounds
Hyge Moving Parts = 1950 Pounds
Specimen Weight - 2020 Pounds
7 May 1973
J. SHAFFER
AMRL/BBI
ACCELERATION - (G'S)
60
50
40
30
20
10
0
20
40
60
80
100
120
140
160
180
SET VOLUME LENGTH, (INCHES)
TOTAL TIME - (ms)
150
125
100
75
50
25
0
TERMINAL VELOCITY - (FT/SEC)
120
100
80
60
40
20
0
- G LEVEL
- TIME
- VELOCITY
3.5' LOAD
5' LOAD
7' LOAD
10' LOAD

Figure 11



HYGE OPERATING CURVES
Trapezoidal Wave Pin
TOTAL TIME
VELOCITY
PRESSURE RATIO
Set Volume Length = 60 inches
Load Volume Length = 60 inches
Set Pressure = 200 psig
Carriage Weight = 1787 Pounds
Hyge Moving Parts = 1950 Pounds
2020 POUND SPECIMEN
18 May 1973
J. SHAFFER
AMRL/BBI
PRESSURE RATIO, Pload/Pset
0
1
2
3
4
5
6
ACCELERATION, G'S
0
5
10
15
20
25
30
35
TERMINAL VELOCITY, FT/SEC
0
10
20
30
40
50
60
70
TOTAL TIME - ms
0
20
40
60
80
100
120
140

Figure 12



HYGE BRAKE PARAMETERS
$P_{BT} = P_{BE} + \frac{2000 + \text{Payload Wt.}}{147}$
P_{BT} = Brake Gauge Pressure
P_{BE} = Effective Brake Pressure
K.E. = $(.0335)(W)(V^2) = (F)(X)$
W = Total Weight in Pounds
V = Max. Carr. Speed in MPH
F = Brake Drag Force
X = Deceleration Distance
22 July 1972
J. SHAFFER
AMRL/BBI
P_{BE} = 230 psig
P_{BE} = 100 psig
P_{BE} = 85 psig
P_{BE} = 70 psig
P_{BE} = 55 psig
P_{BE} = 40 psig
P_{BE} = 25 psig
P_{BE} = 10 psig
P_B = 0 psig
KINETIC ENERGY - FT - LB
1500K
1400K
1300K
1200K
1100K
1000K
900K
800K
700K
600K
500K
400K
300K
200K
100K
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95
CARRIAGE DECELERATION DISTANCE - FT.

REFERENCES

1. Installation and Operating Instructions for HYGE Shock Tester VE No. 38326, The Bendix Corporation, June 1972.

2. Operating Instructions for the Wright-Patterson Impulse Accelerator (WPIA) Safety and Control System - 6570th AMRL, Prepared by Charles S. Clark and Harold F. Boedeker, Dynalectron Corporation, April 1973.

3. Theory of Operation and Maintenance Instructions for the Wright-Patterson Impulse Accelerator Safety and Control System, Charles S. Clark and J. B. Blaylock, Dynalectron Corporation, January 1974.

4. VTD System: Theory of Operation, Charles S. Clark, Dynalectron Corporation, November 1973.

5. Installation and Operation; Air and Gas Compressors, The Norwalk Corporation, Serial No. M-47570.